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Fish Communities in Lakes in Subregion 2B (Upper Peninsula of Michigan) in Relation to Lake Acidity. Volume 1

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FISH COMMUNITIES IN LAKES IN SUBREGION 2B (UPPER PENINSULA OF MICHIGAN) IN RELATION TO LAKE ACIDITY

VOLUME I

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16. ABSTRACT

Surveys of fish community status were conducted in summer 1987 in 49 lakes in Subregion 2B, the Upper Peninsula of Michigan, as part of Phase II of the Eastern Lake Survey. Lake selection involved a variable probability sampling design. Fish communities were surveyed using gill nets, trap nets, beach seines, and angling. Duplicate surveys were conducted for 10 of the 49 lakes as part of the quality assurance/ quality control protocol. Fish were collected in 47 of the 49 lakes surveyed. Extrapolation of the results to the Eastern Lake Survey Phase II target population suggests that 99.4% of the lakes in the area support fish. For the 49 survey lakes, the number of fish species caught per lake (species richness) was lower in seepage lakes (without inlets or outlets) than in non-seepage lakes and was also lower in lakes with lower pH, ANC, calcium (and other base cations), DOC, and silica and with higher levels of extractable aluminum. For several fish species and for cyprinid (minnow) and darter species as a group, lakes without fish had significantly lower levels of pH, ANC, calcium, base cations, silica, and sulfate; were smaller in size; and were more often seepage lakes than non-seepage lakes. In contrast to the large number of variables associated with fish presence/absence and species richness, variations in the numbers of fish caught and catch per unit effort among lakes appeared to be independent of lake characteristics.

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EXECUTIVE SUMMARY

The research described in this document represents one component of Phase II of the Eastern Lake Survey (ELS-II), a part of the National Surface Water Survey (NSWS). Surveys of fish community status were conducted in summer 1987 in 49 lakes in ELS Subregion 2B, the Upper Peninsula of Michigan. Subregion 2B was selected because of its (1) high proportion of acidic (9.8% with ANC ≤ 0 µeq/L) and low-pH lakes (9.4% with pH ≤ 5.0; 17.7% with pH ≤ 6.0), (2) relative lack of existing data on fish communities in lakes, and (3) diverse geological and hydrological conditions allowing optimal evaluation of the association between lake characteristics and fish community status. A companion study dealing with regional patterns in fish mercury content in Subregion 2B was conducted concurrently; results from this study will be presented in a subsequent report (U.S. Environmental Protection Agency [EPA], in prep.).

The NSWS is a survey, not a process-oriented, cause-and effect research program. The emphasis is on developing a regional perspective on the current status of aquatic resources with regard to potential impacts from acidic deposition. Regional surveys of fish community status are needed to quantify the proportion and types of fishery resources in lakes considered potentially sensitive to acidic deposition. In addition, survey correlations between fish community status and water chemistry may be used to evaluate dose-response relationships derived experimentally in laboratory or field bioassays. Thus, the specific objectives of this project were as follows:

- Estimate the percentage (by number and area) of lakes with few or no fish (i.e., with no fish caught in the survey) in Subregion 2B.
- Estimate the percentage (by number and area) of fish populations that occur in lakes with low acid neutralizing capacity (ANC), potentially susceptible to effects from acidic deposition.
- Determine the chemical characteristics of lakes with and without fish (as estimated by catch/no catch).
- Quantify the relationship between fish presence/absence and lake chemical and physical characteristics.
- Quantify the relationship between selected fish population characteristics (e.g., relative abundance and condition factors) and lake chemical and physical characteristics.

The lakes sampled in Subregion 2B during ELS-II to assess fish community status were a subset of the lakes sampled during Phase I of the Eastern Lake Survey (ELS-I). Lake selection involved a variable probability sampling design that (1) concentrated on lakes with low pH, (2) covered the full range of values for dissolved organic carbon (DOC), and (3) attempted to even-out the inclusion probabilities assigned in the ELS-I. Several categories of lakes were excluded from the ELS-II and the ELS-II target population in Subregion 2B: lakes < 1.5 m in depth, larger than 2000 ha, highly enriched with nutrients, or modified by recent in-lake management practices (e.g., recent fish stocking). Lakes smaller than < 4 ha in area were excluded from both the ELS-I and ELS-II target populations.

The 49 ELS-II lakes in Subregion 2B were sampled between 8 June and 30 August 1987. Fish communities were surveyed using gill nets, trap nets, beach seines, and angling. Coincident with the fish surveys, some data on lake physical and chemical parameters were collected (e.g., measures of aluminum speciation). For the most part, however, the ELS-II data on fish communities in lakes in Subregion 2B are interpreted relative to the ELS-I index of lake chemistry collected in fall 1984. It is recognized that the ELS-I data are not direct measures of chemical conditions during those specific times and locales critical to fish population response. It is assumed, however, that the ELS-I index chemistry is at least correlated with these water quality values of interest.

Duplicate surveys of fish communities were conducted for ten of the 49 ELS-II lakes between 31 August and 12 September 1987 as part of the quality assurance/ quality control (QA/QC) protocol. Comparison of results from these duplicate surveys provides some information on sampling errors and variability. In general, measures of species richness (i.e., the number of fish species caught) and fish species presence/absence were similar in the duplicate samples. For species richness, all but one lake had a coefficient of variation (CV) < 50%; all but two of the ten lakes had a CV < 25%. The maximum deviation in species richness between the two samples was two species. Variations in numbers of fish caught and catch per unit effort (CPUE), on the other hand, were somewhat greater (coefficients of variation 10 to 140%). Many factors influence fish capture efficiency, thereby limiting the utility of CPUE as an index of relative fish abundance.

Fish were collected in 47 of the 49 lakes surveyed. The number of species caught per lake ranged between 0 and 13, with a median of three. Thirty-one fish species were caught in total. Yellow perch (Perca flavescens) was the most common species, collected in 31 lakes. Seven other fish species occurred in 10 or more lakes. In decreasing order of frequency, these species were largemouth bass (Micropterus salmoides), bluegill sunfish (Lepomis macrochirus), pumpkinseed sunfish (Lepomis gibbosus), white sucker (Catostomus commersoni), brown bullhead (Ictalurus nebulosus), golden shiner (Notemigonus crysoleucas), and northern pike (Esox lucius). The species caught are typical of those reported for lakes in the Upper Midwest as a whole (including northern Minnesota, Wisconsin, and Michigan).

Extrapolation of these results to the ELS-II target population in Subregion 2B suggests that 99.4% of the lakes in the area (in the defined target population) support fish (99.5% of the lake area). Game species occur in 83.7% of the lakes (95.7% by lake area); 16.6% of the lakes with game fish have ANC ≤ 50 μeq/L (4.0% by lake area). The most common fish species in the subregion are yellow perch (occurring in an estimated 69.8% of the lakes; 88.6% by lake area), white sucker (52.1% and 48.0% of the lakes, by number and area, respectively), and largemouth bass (50.8 and 49.2%).

For the 49 ELS-II lakes, the number of fish species caught per lake (species richness) was lower in seepage lakes (without inlets or outlets) than in nonseepage lakes, and also lower in lakes with lower pH, ANC, calcium (and other base cations), DOC, and silica and with higher levels of extractable aluminum. Many of these variables are themselves highly correlated, however, complicating interpretation of the association between fish community status and lake characteristics.

For several fish species and for cyprinid (minnow) and darter species as a group, lakes without fish had significantly lower levels of pH, ANC, calcium, base cations, silica, and sulfate; were smaller in size; and were more often seepage lakes than nonseepage lakes. In contrast, the distributional patterns for yellow perch, brook trout (Salvelinus fontinalis), central mudminnow (Umbra limi), and brook stickleback (Culaea inconstans) were not consistently associated with any of the measured lake physical or chemical characteristics. Brown bullhead distribution was also unrelated to variations in lake chemistry, although significantly associated with lake elevation. These results are generally consistent with other studies of fish species distribution and sensitivity to acidic conditions. Yellow perch, brown bullhead, brook trout, and central mudminnow are considered relatively acid tolerant, while cyprinids and darters are considered acid sensitive.

In contrast to the large number of variables associated with fish presence/absence and species richness, variations in the numbers of fish caught (and CPUE) among lakes appeared independent of lake characteristics. Only for yellow perch were any statistically significant associations identified: higher numbers of yellow perch were caught in lakes with lower pH, ANC, calcium, sum of the base cations, and silica, and with higher levels of extractable aluminum. Thus, yellow perch are not only tolerant of acidic conditions, but are actually more abundant in acidic waters with lower calcium and silica, perhaps as a result of reduced competition from other fish species.

Survey data alone cannot establish causality. Many factors influence fish distribution, abundance, and condition, and many of these factors are themselves interrelated and correlated. The observed results for the ELS-II in Subregion 2B are, however, consistent with existing hypotheses regarding factors that influence fish community status. For example, seepage lakes tend to have relatively depauperate fish communities, perhaps as a result of their relative isolation and reduced rates of fish colonization. Larger lakes tend to support more diverse fish communities, reflecting the generally greater habitat complexity in larger lakes. The ELS-II data also suggest a negative effect of low ionic strength (i.e., low concentrations of calcium and other base cations) and lake acidity (low pH and ANC) on several fish species and groups.

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1. INTRODUCTION AND BACKGROUND

1.1 THE NATIONAL SURFACE WATER SURVEY

In 1983, the U.S. Environmental Protection Agency (EPA) initiated the National Surface Water Survey (NSWS) to document the chemical and biological status of lakes and streams in regions of the United States potentially susceptible to acidic deposition. The NSWS was designed as a three-phase project:

- Phase I — a synoptic survey of lake and stream chemistry.
- Phase II — an evaluation of chemical variability and biological status for a subset of surface waters in selected regions sampled during Phase I.
- Phase III — a long-term monitoring program to quantify future changes in the chemistry and biology of aquatic ecosystems characteristic of geographic regions of the United States. Phase III of the NSWS has since been subsumed within the broader EPA monitoring program, Temporally Integrated Monitoring of Ecosystems (TIME).

The NSWS consists of two major components: the National Lake Survey and the National Stream Survey. The National Lake Survey consists, in turn, of the Eastern Lake Survey (ELS) and Western Lake Survey (WLS). The research described in this document represents one component of Phase II of the Eastern Lake Survey (ELS-II).

Phase I of the ELS (ELS-I) was conducted in fall 1984, with the final results presented in three volumes (Linthurst et al. 1986, Overton et al. 1986, Kanciruk et al. 1986). The ELS-I had three primary objectives:

1. to determine the percentage (by number and area) and location of lakes that are acidic in potentially sensitive regions of the eastern United States,
2. to determine the percentage (by number and area) and location of lakes that have low acid neutralizing capacity (ANC) in potentially sensitive regions of the eastern United States, and
3. to determine the chemical characteristics of lake populations in potentially sensitive regions of the eastern United States and provide the data base for selecting lakes for future study.

To accomplish these objectives, a water sample was collected during fall overturn at 1.5 m depth over the deepest point in the lake from 1612 lakes within 11 subregions in the northeastern, southeastern, and upper midwestern regions of the United States (Figure 1-1). A suite of chemical variables and physical attributes thought to influence or be influenced by surface water acidification was measured for each lake. Lakes sampled were selected by a systematic random process from the population of lakes in

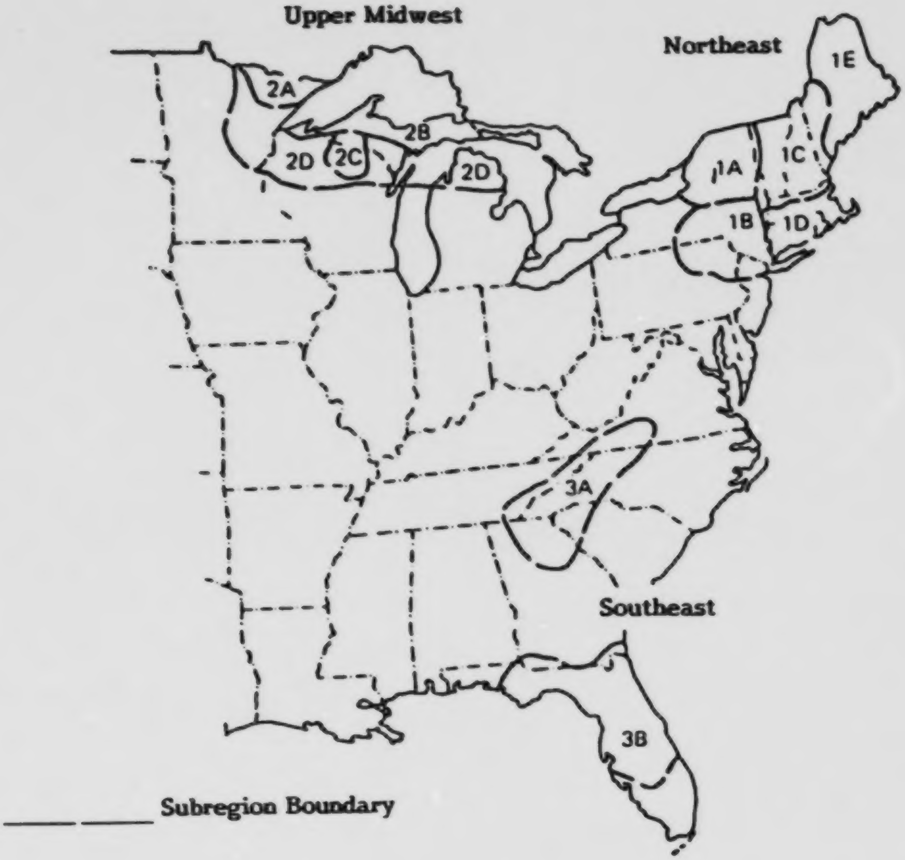
Upper Midwest
Northeast
1E
2A
2B
1C
2D
2C
2D
1A
1B
1D
3A
Southeast
3B
Subregion Boundary

Figure 1-1. Subregions surveyed during Phase I of the Eastern Lake Survey.

the areas studied. Thus, the ELS-I data base provides the basis for regional estimates of the chemical status of lakes within a specific region or subregion.

Three subregions sampled during ELS-I had the highest frequency and number of acidic (defined by an ANC ≤ 0 μeq/L) and low pH lakes (Table 1.1):

1. Subregion 3B (Florida), with an estimated 476 (22.7%) acidic lakes, 259 (12.4%) lakes with pH ≤ 5.0, and 687 (32.7%) lakes with pH ≤ 6.0;

2. Subregion 1A (Adirondacks), with an estimated 181 (14.0%) acidic lakes, 128 (10.0%) lakes with pH ≤ 5.0, and 343 (26.6%) lakes with pH ≤ 6.0; and

3. Subregion 2B (Upper Peninsula of Michigan), with an estimated 119 (11.3%) acidic lakes, 99 (9.4%) lakes with pH ≤ 5.0, and 185 (17.7%) lakes with pH ≤ 6.0.

Table 1.1. **Population Percentage Estimates for Selected pH and ANC Criteria, from Phase I of the Eastern Lake Survey (Lakes ≤2000 ha) (Linthurst et al. 1986, Landers et al. 1988)**

Region/Subregion	Number of Lakes	ANC (µeq/L)[a]			pH	
		≤0	≤50	≤200	≤5.0	≤6.0
Northeast (1)						
Adirondacks (1A)	1290	14.0	37.8	73.0	10.0	26.6
Poconos/Catskills (1B)	1479	5.9	13.5	40.9	0.8	7.8
Central New England (1C)	1483	4.2	23.3	67.6	1.7	12.9
Southern New England (1D)	1318	6.5	22.6	57.3	5.0	14.6
Maine (1E)	1526	1.6	14.7	66.8	0.5	4.8
Upper Midwest (2)						
Northeastern Minnesota (2A)	1457	0.0	5.2	52.1	0.0	1.4
Upper Peninsula of Michigan (2B)	1050	11.3	19.6	41.7	9.4	17.7
Northcentral Wisconsin (2C)	1480	8.7	41.8	57.1	2.1	27.7
Upper Great Lakes Area (2D)	4515	0.0	9.8	31.3	0.0	4.5
Southeast (3)						
Southern Blue Ridge (3A)	258	0.0	1.4	34.3	0.0	0.4
Florida (3B)	2098	22.7	39.8	55.1	12.4	32.7

[a] Population estimates based on recalculated ANC values (Hillman et al., in prep.)

Subregion 2B, encompassing the majority of the Upper Peninsula of Michigan plus a small portion of northern Wisconsin, was selected for the ELS-II survey of fish community status because of (1) the high proportion of acidic and low pH lakes in the subregion, (2) the relative lack of existing data on fish communities in lakes in the area, and (3) the diversity of geological and hydrological conditions in the subregion, allowing optimal evaluation of the association between lake characteristics and fish community status.

1.2 PROJECT OBJECTIVES

The NSWS is a survey, not a process-oriented, cause-and-effect research program. The emphasis is on developing a regional perspective on the current status of aquatic resources with regard to potential impacts from acidic deposition. Regional surveys of fish community status are needed to quantify the proportion and types of fishery resources in lakes considered potentially susceptible to or impacted by acidic deposition. In addition, survey correlations between fish community status and water chemistry may corroborate, in a field situation, dose-response relationships derived experimentally in laboratory and field bioassays. The study described in this document is unique in providing data on fish community status for a defined probability sample of lakes using consistent sampling techniques across a broad region.

The specific objectives of the project are as follows:

- Estimate the percentage (by number and area) and location of lakes with few or no fish (i.e., with no fish caught in the survey) in Subregion 2B (Upper Peninsula of Michigan).
- Estimate the percentage (by number and lake area) of fish populations (by species) that occur in lakes in Subregion 2B with low ANC, potentially susceptible to effects from acidic deposition.
- Determine the chemical characteristics of lakes with and without fish (as estimated by catch/no catch).
  - Do lakes with no fish caught (or without certain fish species) have significantly lower pH (and/or higher aluminum [Al], lower calcium [Ca], or lower dissolved organic carbon [DOC] levels) than do lakes with fish?
- Quantify the relationship between fish presence/absence (by species) and lake chemical and physical characteristics.
  - Are the pH, inorganic Al, and Ca levels associated with the absence of fish species comparable to levels toxic to fish in laboratory and field bioassays?
- Quantify the relationship between selected fish population characteristics (e.g., relative abundance and condition factors) and lake characteristics.

In conjunction with this study of fish community status in lakes in the Upper Peninsula of Michigan, data were also collected on fish mercury content, to assess the relationship between lake characteristics and mercury bioaccumulation. Results from this component of the project are reported in a separate document (EPA, in prep.).

1.3 REPORT FORMAT

The report is divided into 11 sections:

- **Section 1, Introduction and Background**
- **Section 2, Lake Selection** — provides an overview of the statistical sampling design for the ELS-I and the procedures for selecting the subset of lakes sampled in ELS-II.

- **Section 3, Field Implementation** — describes the field sampling methodology for water chemistry and fish communities.

- **Section 4, Quality Assurance/Quality Control (QA/QC)** — summarizes the QA/QC results for field sampling and laboratory analyses.

- **Section 5, Lake Physical Characteristics** — describes the physical characteristics of the lakes sampled, relative to the physical characteristics of lakes in the region as a whole.

- **Section 6, Lake Chemical Characteristics** — summarizes results from water chemistry measurements for ELS-II relative to results for ELS-I, and for the lakes sampled in ELS-II relative to the population of lakes in the region as a whole.

- **Section 7, Fish Community Status** — describes the characteristics of fish communities in lakes in the region, including information on species composition, relative abundance, and fish condition factors.

- **Section 8, Association Between Fish Community Status and Lake Characteristics** — discusses the degree to which among-lake variations in fish community characteristics are associated with variations in lake chemistry and other lake characteristics.

- **Section 9, Regional Population Estimates** — provides regional estimates of the percentage (by number and lake area) of lakes with few or no fish in Subregion 2B, and the proportion of the fishery resource in low-ANC waters.

- **Section 10, Discussion and Summary**

- **Section 11, References**

Two appendices are provided under separate cover (Volume II): Appendix A describes in further detail the QA/QC protocols for measurements of water chemistry, and Appendix B summarizes the data collected during ELS-I and ELS-II for each lake sampled during the ELS-II.

2. LAKE SELECTION

2.1 EASTERN LAKE SURVEY - PHASE I

The lakes sampled in Subregion 2B to assess fish community status were a subset of the lakes sampled during ELS-I. Procedures for lake selection for the ELS-I survey were described in Linthurst et al. (1986) and Landers et al. (1988) and are summarized below.

2.1.1 The Target Population

The study area for ELS-I was restricted to those areas of the United States where the majority of lakes were expected to have ANC < 400 µeq/L, as delineated on the national map of surface water alkalinity prepared by Omernik and Powers (1983) (see Figure 1-1). Within this study area, all lakes appearing on 1:250,000-scale topographic maps from the U.S. Geological Survey (USGS) were identified and labeled. These lakes define the "statistical frame" or "frame population." Lakes with a surface area of < 4 ha (and up to 10 ha on some maps) are generally not shown on maps of this scale and thus were not considered in the survey. The target population of lakes, for which regional estimates are computed, consists of the frame population minus several categories of non-interest lakes. Categories of non-interest lakes excluded from the ELS-I target population include the following:

- **No lake present** — lakes initially identified on 1:250,000-scale maps that did not appear on larger-scale maps (1:25,000- or 1:62,500-scale maps) or that were found to be dry during the site visit.
- **Flowing water** — sites identified as flowing water (streams, rivers) on larger-scale maps or during the site visit.
- **Bay/Estuary (high conductance)** — lakes appearing as ocean embayments or estuaries or with a measured specific conductance > 1500 µS/cm.
- **Urban/Industrial/Agricultural** -- lakes surrounded by or adjacent to intense anthropogenic activities.
- **Marsh/Swamp** — lakes appearing as swamps or marshes on larger-scale maps.
- **Too Shallow** — lakes that were too shallow to collect a clean water sample, free of debris and sediment.
- **Too Small** — lakes less than 4 ha in area based on the larger-scale maps.
- **Other** — lakes that were inaccessible due to a permanent feature of the lake (e.g., power lines that prevented helicopters from landing safely).

In Subregion 2B, the frame population consists of 1698 lakes, with an estimated 1050.0 lakes in the target population (Table 2.1). The majority of the lakes eliminated from the frame population were either too small (< 4 ha) or too shallow.

Table 2.1. Description of the Sample and Target Population for the Eastern Lake Survey - Phase I (ELS-I) and Phase II (ELS-II) for Subregion 2B, the Upper Peninsula of Michigan

Exclusion Category	Stratum			Subregion Total
	2B1	2B2	2B3	
Lakes in the ELS-I frame population	118	250	1330	1698
Lakes in the ELS-I probability sample	74	100	80	254
ELS-I weighting factor (W1)	1.878	2.579	17.208	
Lakes sampled for ELS-I	41	57	48	146
Lakes sampled for ELS-I within the ELS-II target population	36	45	24	105
Estimated target population size ($\hat{N}$)				
ELS-I	77.0	147.0	826.0	1050.0
ELS-II	67.61	116.1	413.0	596.7
Standard error of $\hat{N}$				
ELS-I	4.89	9.83	71.69	72.5
ELS-II	2.72	6.27	58.46	58.9
Estimated lake area (ha) of the target population ($\hat{A}$)				
ELS-I	893	2,776	30,357	34,026
ELS-II	811	1,777	12,493	15,081
Standard error of $\hat{A}$				
ELS-I	90	500	10,842	10,854
ELS-II	77	269	4,601	4,609

2.1.2 Statistical Design

The sampling plan for ELS-I used a stratified design with equal allocation of sample lakes among strata. Lakes were selected from each stratum by systematic sampling of an ordered list following a random start.

The three regions, Northeast, Southeast, and Upper Midwest (Figure 1-1), represented the first level of stratification. Subregion, the second stratification factor, identified areas within each region that were expected to be relatively homogeneous with respect to water quality, physiography, vegetation, climate, and soils. Four subregions were defined in the Upper Midwest region (Region 2): 2A (Northeastern Minnesota), 2B (Upper Peninsula of Michigan), 2C (Northcentral Wisconsin), and 2D (Upper Great Lakes Area) (Figure 1-1). Eleven subregions were defined in total: four in the Upper Midwest, five in the Northeast, and two in the Southeast.

The third stratification factor, alkalinity map class, differentiated among areas within each subregion based on the range of surface water alkalinity values expected to dominate in different areas. The alkalinity map classes chosen were < 100 µeq/L (class 1), 100-200 µeq/L (class 2), and > 200 µeq/L (class 3). Spatial representations of the three alkalinity classes within each subregion were derived from preliminary versions of regional surface water alkalinity maps prepared by Omernik and Kinney (1985), Omernik and Griffith (1985), and Omernik (1985). All three alkalinity map classes were found within each of the 11 subregions. Thus, a total of 33 strata was defined. Strata are coded by region, subregion, and alkalinity map class; for example, 2B1 designates the Upper Midwest Region (2), the Upper Peninsula of Michigan Subregion (B), and alkalinity map class 1.

Map class boundaries according to region, subregion, and alkalinity class were identified on 1:250,000-scale USGS maps. All lakes represented on the map were assigned a unique number, numbered consecutively according to location within the mapping unit. Within each stratum, lakes were selected for sampling as a systematic random sample. Non-target lakes, as defined in Section 2.1.1, were then eliminated by examining larger-scale maps or during field operations. Approximately 50 lakes in the target population were sampled per stratum, with a total of 146 lakes sampled in Subregion 2B (Table 2.1, Figure 2-1).

For extrapolation from the sample of lakes to the target population within a subregion or region, the sample data must be weighted by stratum-specific weights. The

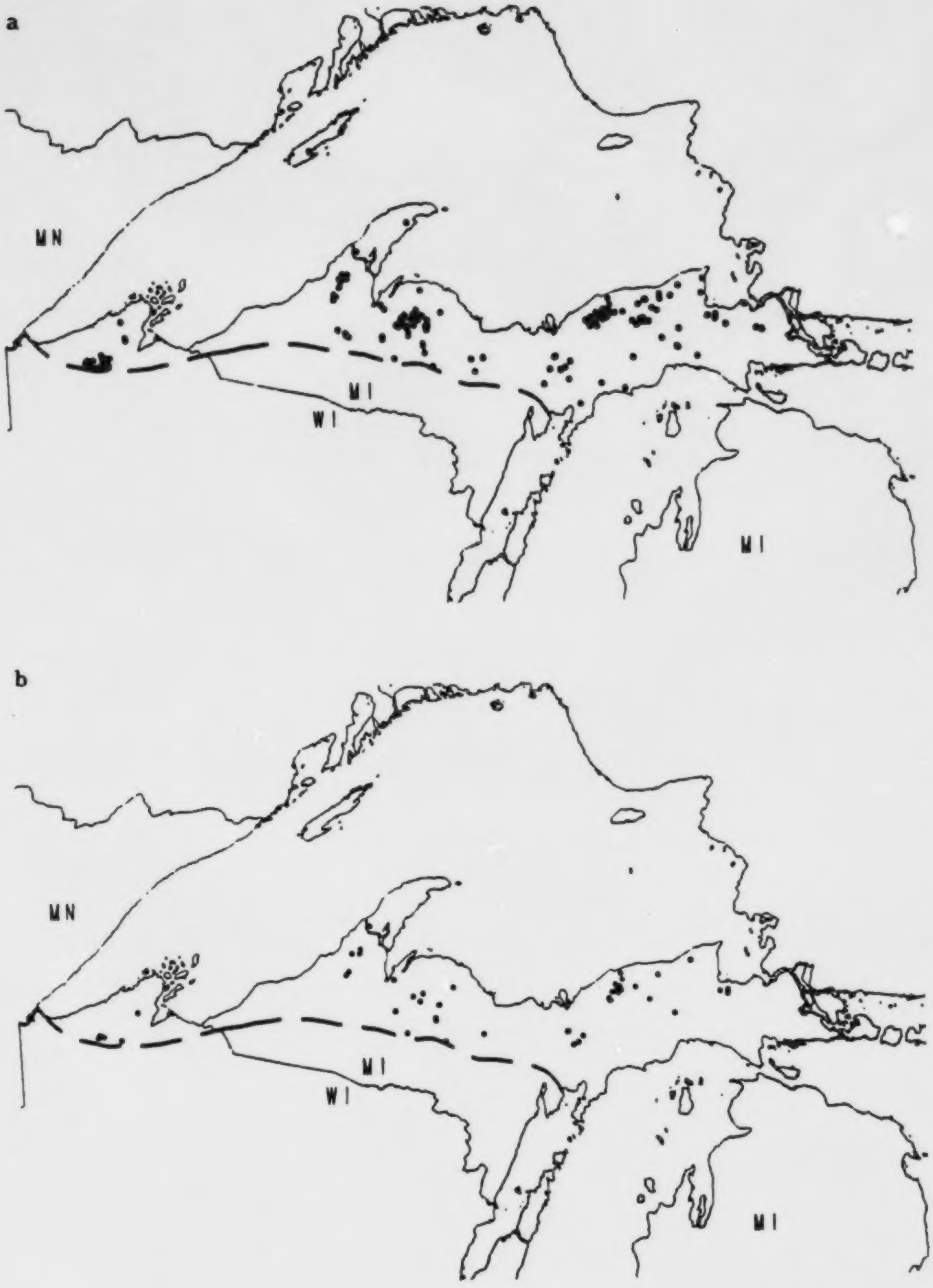
a
MN
MI
WI
MI
b
MN
MI
WI
MI

Figure 2-1. Geographic distribution of the lakes sampled in Subregion 2B during (a) ELS-I and (b) ELS-II.

ELS-I weighting factors (W1) for Subregion 2B are presented in Table 2.1 and are calculated as follows:

$$W1 = \frac{N^*}{n^*}$$

where:

N^* = the number of lakes in the frame population, and

n^* = the number of lakes in the original ELS-I probability sample (including non-interest lakes).

The estimated ELS-I target population size ($\hat{N}$) for each stratum is then calculated as:

$$\hat{N} = W1(n^{***})$$

where:

n^{***} = the number of lakes sampled during ELS-I in the target population.

Procedures for calculating the variance and standard errors of population estimates are outlined in Linthurst et al. (1986).

2.2 SURVEYS OF FISH COMMUNITY STATUS (ELS-II)

Fifty lakes in Subregion 2B were selected for surveys of fish community status as part of ELS-II. Lakes to be surveyed were selected as a variable probability systematic sample from among those lakes sampled during ELS-I. This approach is consistent with the probability sampling frame used during ELS-I and was designed to optimize assessment of the influence of key water chemistry variables on fish community status and fish mercury content.

2.2.1 The Target Population

The ELS-I target population (Section 2.1.1) was further refined to eliminate classes of lakes considered of little or no interest relative to the ELS-II objectives:

- shallow lakes (site depth < 1.5 m), subject to winterkill and therefore unlikely to support a significant fishery resource;
- very large lakes (> 2000 ha), likely to exhibit considerable spatial variability and thus difficult to adequately characterize both chemically and biologically;

- lakes highly enriched with nutrients that may distort the chemical composition of the lakes and confound data interpretation; criteria include any of the following:
  - total phosphorus (P) > 90 µeq/L
  - nitrate (NO_3) > 50 µeq/L
  - ammonia (NH_4) > 30 µeq/L
  - turbidity > 7 NTU
  - Secchi depth < 0.5 m
- lakes modified by recent in-lake management practices resulting in a disturbance of either biota or lake chemistry (e.g., recent stocking, lake liming, rotenone treatment, dam removal);
- lakes modified by anthropogenic disturbances to such an extent that the results would not be representative of other lakes in the population (e.g., major wastewater treatment plant discharge into the lake);
- reservoirs less than 10 years old that may have experienced recent, major influxes and mobilization of mercury associated with flooding land surfaces; and
- lakes heavily impacted by road salt or chloride (Cl) from other anthropogenic sources (Cl > 100 µeq/L), given that high levels of Cl may enhance mercury mobilization and mask any potential influence of lake acidity on mercury bioaccumulation.

Of the 146 lakes in Subregion 2B sampled in ELS-I, 41 were eliminated based on the above exclusion criteria. Many of the lakes excluded (61%) were too shallow, with a site depth < 1.5 m (Table 2.2). From the remaining 105 lakes sampled in ELS-I, 50 lakes were selected for sampling in ELS-II, as described in Section 2.2.2.

The ELS-II target population size can be estimated in the same manner as described in Section 2.1.2 for the ELS-I target population, adjusting for the change in the number of ELS-I lakes sampled within the ELS-II target population. The weighting factors per stratum do not change. The estimated size of the redefined ELS-II target population is 596.7 lakes, as opposed to an estimated target population for ELS-I of 1050.0 lakes, in Subregion 2B (Table 2.1).

2.2.2 Statistical Design

Lake pH, inorganic Al, Ca, and DOC are considered the four chemical variables most likely to influence fish community status and fish mercury content in acidic lakes (Driscoll at al. 1980, Brown 1983, Altshuller and Linthurst 1984, Quinn and Bloomfield

Table 2.2. Numbers of ELS-I Lakes Excluded from the ELS-II Target Population in Subregion 2B

Exclusion Category[a]	Stratum 2B1	Stratum 2B2	Stratum 2B3	Subregion Total
Site Depth <1.5 m	1	6	18	25
Lake Area >2000 ha	0	0	0	0
High Nutrients				
P >90 µeq/L	0	0	1	1
NO_3 >50 µeq/L	0	0	0	0
NH_4 >30 µeq/L	0	0	0	0
Turbidity >7 NTU	0	0	0	0
Secchi Depth <0.5 m	0	1	0	1
Modified by Recent In-Lake Management	4	4	44	12
Anthropogenic Disturbances	0	0	0	0
Recent Reservoir	0	0	1	1
Cl >100 µeq/L	0	1	3	4
Total No. Lakes	5	12	24	41

[a] Lakes may fit within more than one exclusion category; thus, the total number of lakes excluded may be less than the sum of the individual categories.

1985). Levels of inorganic Al were not measured during ELS-I (Linthurst et al. 1986). Levels of Ca and pH measured during ELS-I in Subregion 2B were highly correlated (Figure 2-2). Thus, pH and DOC (Figure 2-3) were chosen as the two most important factors to consider in lake selection.

The objectives of the sampling design were to select a probability subsample of lakes from the ELS-I sample for Subregion 2B that (1) concentrated on lakes with low pH, (2) covered the full range of DOC values, and (3) attempted to even-out the inclusion probabilities (i.e., the inverse of the weighting factor) assigned in ELS-I. The following methodology was used to select a subsample of 50 lakes for ELS-II from the 105 lakes sampled during ELS-I in the ELS-II target population.

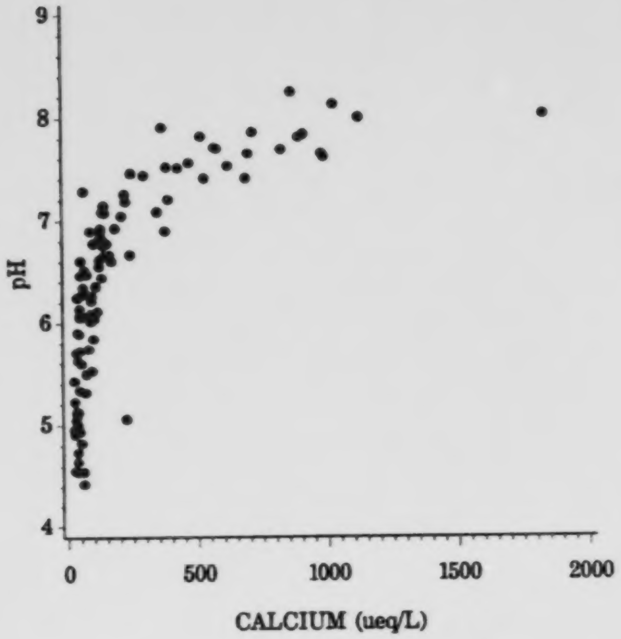

Figure 2-2. Relationship between pH and Ca for the 105 lakes in Subregion 2B sampled during ELS-I and in the ELS-II target population.

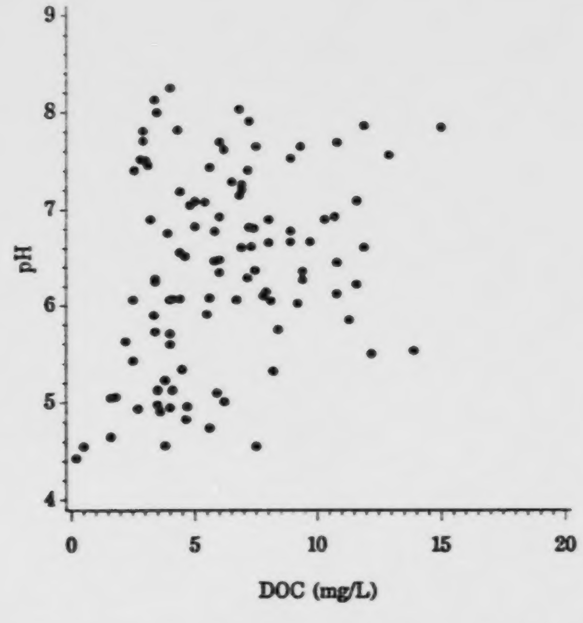

Figure 2-3. Relationship between pH and DOC for the 105 lakes in Subregion 2B sampled during ELS-I and in the ELS-II target population.

For each lake, the function z_i was calculated:

$$z_i = (pH^{-7}) \bullet W1 \bullet 10^4$$

where pH is the lake pH (closed system) measured in ELS-I, and W1 is the ELS-I weighting factor (Table 2.1). Inclusion of $(pH)^{-7}$ in the calculation of z_i increases the probability of selecting lakes with lower pH levels, i.e., those lakes most likely to have fish communities potentially impacted by acidification or higher levels of fish mercury content resulting from lake acidity. The constant, 10^4, is an arbitrary value used to adjust the scale of the function.

The 105 lakes were then ordered by DOC, and lakes to be sampled during ELS-II were selected from this ordered list by randomly picking a starting point and choosing every Kth lake, where the distance between lakes is z_i. The sampling interval (K) for selection of the systematic sample is defined by

$$K = \frac{\sum z_i}{n}$$

where:

n = the number of lakes to be selected.

Thus, lakes for ELS-II were selected using a variable probability systematic procedure with an inclusion probability for each lake proportional to z_i (Cochran 1977).

A number of lakes with low pH and/or a high value for W1 had $z_i > K$; as a result, the probability of choosing these lakes in the sample is 100%. It was necessary, therefore, to identify these lakes and to remove them from the lake list prior to initiating the variable probability systematic sample selection. The initial value for K (K_1) with n=50 was 0.39114. All lakes with z_i exceeding this value (n=11) were edited from the lake list and were automatically included in the ELS-II sample. A new value for K (K_2) was calculated based on the 94 lakes remaining and with n=39 (50-11). Ten additional lakes had z_i values exceeding the new value of K (K_2=0.23889), and thus were also edited from the lake list and were included in the ELS-II sample. The process was repeated a third time, with a third recalculated value for K (K_3=0.22638). Two lakes had $z_i > K_3$. Thus, 23 lakes were assigned to the ELS-II subsample with a conditional inclusion probability (p_c) of 1, leaving 27 lakes to be drawn based on a variable probability systematic sample from the remaining 82 ELS-I lakes (K_4=0.22581).

For the 23 lakes selected with a p_c of 1, the ELS-II weighting factor (W2) equals the ELS-I weighting factor (W1). For all other ELS-II lakes, the weighting factor is calculated as

$$W2 = W1 \frac{K_4}{z_i}$$

Values for z_i, W1, and W2 for the 50 lakes in Subregion 2B selected for sampling during ELS-II are listed in Table 2.3. The estimated size ($\hat{N}$) and area ($\hat{A}$) of the ELS-II target population of lakes, based on this sample of 50 lakes and the ELS-II weighting factors, are as follows:

$$\hat{N} = 642.3$$

$$\text{Std. Error } (\hat{N}) = 100.4$$

$$\hat{A} = 22{,}008 \text{ ha}$$

$$\text{Std. Error } (\hat{A}) = 10{,}920 \text{ ha}$$

The distinction between these estimates and those in Table 2.1 derived from the ELS-I weighting factors (W1) for the 105 ELS-I lakes in the ELS-II target population should be noted.

At the request of the Michigan Department of Natural Resources, Lake 2B1-065 (Penegor Lake) was deleted from the list of lakes to be surveyed to avoid interference with an ongoing study of fish populations in the lake. Excluding this lake from the survey does not require redefinition of the ELS-II target population. Thus, 49 lakes in Subregion 2B were sampled during ELS-II (Figure 2-1).

Table 2-3. List of Lakes Selected for ELS-II in Subregion 2B

Lake ID	DOC	pH	ELS-I Weighting Factor (W1)	z_i[a]	ELS-II Weighting Factor (W2)
2B1-016	11.30	5.85	1.878	0.08009	5.2947
2B1-022	3.35	5.90	1.878	0.07546	5.6197
2B1-035[b]	4.70	4.96	1.878	0.25429	1.8780
2B1-038[b]	3.80	4.56	1.878	0.45808	1.8780
2B1-039[b]	3.50	4.98	1.878	0.24722	1.8780
2B1-040[b]	5.60	4.74	1.878	0.34934	1.8780
2B1-041	4.10	5.13	1.878	0.20085	2.1114
2B1-042[b]	6.20	5.01	1.878	0.23705	1.8780
2B1-047[b]	0.50	4.55	1.878	0.46517	1.8780
2B1-048[b]	0.20	4.43	1.878	0.56088	1.8780
2B1-052[b]	4.00	4.95	1.878	0.25790	1.8780
2B1-061	1.60	5.05	1.878	0.22421	1.8914
2B1-064	1.80	5.06	1.878	0.22113	1.9178
2B1-065[c]	8.20	5.32	1.878	0.15571	2.7235
2B1-066[b]	1.60	4.65	1.878	0.39951	1.8780
2B2-004	7.90	6.14	2.579	0.07839	7.4290
2B2-007	2.50	5.43	2.579	0.18529	3.1430
2B2-024	8.40	5.75	2.579	0.12410	4.6927
2B2-038	7.40	6.81	2.579	0.03797	15.3385
2B2-044[b]	3.80	5.23	2.579	0.24096	2.5790
2B2-049[b]	5.90	5.10	2.579	0.28738	2.5790
2B2-055[b]	7.50	4.55	2.579	0.63881	2.5790
2B2-061	13.90	5.53	2.579	0.16307	3.5713
2B2-074	6.00	6.35	2.579	0.06195	9.4008
2B2-075	5.50	5.91	2.579	0.10241	5.6867
2B2-078	2.20	5.63	2.579	0.14384	4.0486
2B2-079	4.40	6.07	2.579	0.08494	6.8560
2B2-082	4.00	5.60	2.579	0.14933	3.9000
2B2-090[b]	3.50	5.13	2.579	0.27582	2.5790
2B2-098	10.30	6.90	2.579	0.03463	16.8150
2B2-100[b]	4.65	4.83	2.579	0.42055	2.5790
2B3-007[b]	4.40	6.56	17.208	0.32916	17.2080
2B3-008[b]	8.90	6.78	17.208	0.26129	17.2080
2B3-009	11.90	7.86	17.208	0.09285	41.8511
2B3-012	10.70	6.93	17.208	0.22418	17.3333
2B3-013[b]	2.70	4.94	17.208	2.39685	17.2080
2B3-020[b]	7.80	6.10	17.208	0.54755	17.2080
2B3-023	9.30	7.65	17.208	0.11223	34.6244
2B3-027	4.00	8.25	17.208	0.06615	58.7394
2B3-028	7.15	7.41	17.208	0.14028	27.6998
2B3-030[b]	4.49	5.34	17.208	1.38976	17.2080
2B3-031	6.80	8.03	17.208	0.07993	48.6137
2B3-034	6.17	7.62	17.208	0.11536	33.6849
2B3-037	3.46	8.00	17.208	0.08205	47.3565
2B3-051[b]	3.60	4.91	17.208	2.50127	17.2080
2B3-055	2.54	7.41	17.208	0.14028	27.6998
2B3-056[b]	8.00	6.90	17.208	0.23109	17.2080
2B3-057[b]	5.00	6.83	17.208	0.24819	17.2080
2B3-058[b]	3.40	6.25	17.208	0.46192	17.2080
2B3-071	4.80	7.05	17.208	0.19880	19.5467

[a] $z_i = W1*(pH^{-7})*10^4$.
[b] Lakes selected with $p_c=1$.
[c] Lake not surveyed at the request of the Michigan Department of Natural Resources.

3. FIELD IMPLEMENTATION

Field activities at each lake included (1) an initial lake reconnaissance; (2) in situ measurements of pH, conductivity, dissolved oxygen (DO), temperature, and Secchi depth; (3) collection of water and sediment samples for subsequent chemical analysis; (4) sampling of fish communities; and (5) preservation of a sample of fish for analysis of tissue mercury content. Procedures for field sampling were described in detail in the Field Training and Operations Manuals for the study (Fabrizio and Taylor 1987, Hagley et al. 1987) and are summarized below. Activities and analyses specific to the study of fish mercury content are described in EPA (in prep.).

3.1 FIELD PERSONNEL

Biological and chemical sampling operations were conducted concurrently. Personnel from Michigan State University conducted fish sampling operations. Personnel from Lockheed Engineering & Sciences Company collected water samples, sediment samples, and in situ chemistry measurements. The 49 lakes were sampled by two field crews, with five individuals per crew. All field personnel participated in a two-day field training program (27-28 May 1987) on the field sampling protocol and QA/QC procedures. This program provided hands-on experience with gear deployment, fish handling procedures, fish identification, fish measurements, boat and trailer handling, and proper data entry. Field crew leaders were given additional training in lake reconnaissance, QA/QC procedures, and personnel management.

3.2 SAMPLING PERIOD

The 49 ELS-II lakes in Subregion 2B were sampled between 8 June and 30 August 1987 (Table 3.1). Ten lakes were resurveyed as part of the QA/QC protocol (Section 4) between 31 August and 12 September 1987. In general, each lake was sampled over a two-day period. Routine water sampling and fish net placement occurred on the first day. During the second day, nets were retrieved and fish measured and processed.

Subregion 2B was subdivided into three zones corresponding with the location of the three field base stations in Munising, MI; L'Anse, MI; and Iron River, WI. Within a given zone, lake order for sampling was originally assigned at random to minimize potential biases associated with any change in fish capture efficiency over time. Some alteration of this predetermined schedule was necessary, however, due to problems with lake access and a delay in initiating field sampling.

Table 3.1. Sampling Dates (1987) and Fish Sampling Effort Per Lake

Lake ID	Area (ha)	Sampling Date	Units of Effort[a]			
			Gill Net	Trap Net	Seine	Angling
2B1-016	4.2	24-25 Jun	3[b]	3	0[c]	2
2B1-022	8.6	24-25 Jun	3	3	0[c]	2
		31 Aug-1 Sep	3	3	4	2
2B1-035	4.3	5-6 Aug	3	3	4	2
2B1-038	6.3	20-21 Aug	3	3	4	2
		10-11 Sep	3	3	4	2
2B1-039	15.7	18-19 Jun	3	3	0[c]	1[c]
2B1-040	4.5	18-19 Jun	3	3	0[c]	2
2B1-041	19.7	10-11 Aug	4	4	5	2
2B1-042	8.3	5-6 Aug	3	3	4	2
2B1-047	16.7	13-14 Aug	3	3	4	2
2B1-048	49.8	12-13 Aug	6	6	6	2
2B1-052	4.5	12-13 Aug	3	3	3[c]	2
2B1-061	6.4	24-25 Aug	3	3	4	2
2B1-064	8.5	20-21 Aug	3	3	4	2
2B1-066	14.7	6-7 Aug	3	3	4	2
2B2-004	8.1	22-23 Jun	3	3	0[c]	2
2B2-007	6.3	16-17 Jul	3	3	4	2
2B2-024	8.1	8-9 Jul	3	3	4	2
2B2-038	5.5	27-28 Aug	3	3	4	2
2B2-044	4.7	24-25 Aug	3	3	4	2
2B2-049	5.0	30-31 Jul	3	3	0[c]	2
		8-9 Sep	3	3	3[c]	2
2B2-055	4.9	30-31 Jul	3	3	4	2
2B2-061	20.6	1-2 Jul	4	4	5	2
2B2-074	11.0	23-24 Jun	3	3	4	2
		1-2 Sep	3	3	4	2
2B2-075	9.5	26-27 Jun	3	3	0[c]	2
		31 Aug-1 Sep	3	3	4	2
2B2-078	4.5	13-14 Jul	3	3	3[c]	2
		2-3 Sep	3	3	4	2
2B2-079	9.0	22-23 Jul	3	3	4	2
2B2-082	4.4	13-14 Jul	3[d]	3	4	2
2B2-090	5.5	14-15 Jul	3	3	4	2

(continued)

Table 3.1. Continued

Lake ID	Area (ha)	Sampling Date	Units of Effort[a]			
			Gill Net	Trap Net	Seine	Angling
2B2-098	26.2	6-7 Jul	1[c]	4	0[c]	2
2B2-100	12.7	2-3 Jul	3	2[c]	4	2
		8-9 Sep	3	3	4	2
2B3-007	11.6	20-21 Jul	3	3	4	2
2B3-008	4.4	27-28 Aug	3	3	0[c]	2
2B3-009	262.3	3-4 Aug	8	8	8	2
2B3-012	16.7	6-7 Jul	3	3	4	2
2B3-013	4.6	17-18 Aug	3[d]	3	4	2
2B3-020	9.7	15-16 Jul	3	3	0[c]	2
2B3-023	63.2	29-30 Jun	7[e]	7	8	2
2B3-027	21.7	30 Jun-1 Jul	4	4	5	2
2B3-028	32.3	8-9 Jun	5[b]	5	5	2
2B3-030	14.7	15-16 Jun	3	3	4	2
2B3-031	38.0	10-11 Aug	5	5	5	2
2B3-034	16.8	11-12 Jul	3	3	3[c]	2
2B3-037	7.6	28-29 Jul	3	3	4	2
		11-12 Sep	3	3	4	2
2B3-051	6.6	17-18 Aug	3	3	4	2
2B3-055	5.5	28-29 Jul	3	3	4	2
2B3-056	9.1	22-23 Jul	3	3	4	2
2B3-057	18.5	7-8 Jul	3	3	0[c]	2
		3-4 Sep	3	3	4	2
2B3-058	13.2	9-10 Jul	3	3	4	2
		2-3 Sep	3	3	4	2
2B3-071	21.7	15-16 Jun	4	4	5	2

[a] Units of effort:
Gill net and trap net — Number of nets set overnight
Seine — Number of hauls
Angling — Hours

[b] Problems setting gear, with potential reductions in gear effectiveness.

[c] Sampling effort less than proposed (standard) sampling effort; see Table 3.3.

[d] One gill net set deeper than desired, but still fished effectively.

[e] All nets set during the day for a shorter period of time (10-13 h), but still fished effectively.

Twenty-seven lakes were sampled from the Munising base station: 6 lakes at the beginning of the sampling period (8 to 19 June) and 21 lakes at the end of the sampling period (28 July to 30 August). The five lakes in Wisconsin were sampled from the Iron River base station between 22 and 27 June. The 17 lakes near the L'Anse base station were sampled 29 June to 23 July.

It is not expected that the variation in sampling dates, distributed over the three-month sampling period, had a significant effect on the survey results or on the observed patterns in fish community status. Except for lake elevation (Spearman's rank correlation coefficient, r=-0.41), sampling date and lake characteristics were not significantly correlated (at $\alpha=0.05$ adjusted for 14 tests, $p > 0.0036$) (Table 3.2). Analyses to evaluate the potential influence of sampling date on sampling efficiency are discussed further in Section 4.2.

Table 3.2. Nonparametric Correlation Between Sampling Date and Lake Characteristics

Variable	Spearman's Rank Correlation Coefficient
Lake Area	-0.30
Depth	0.12
Elevation	-0.41*
Secchi Depth	0.22
pH	-0.33
Ca	-0.21
DOC	-0.32
Al, Extractable	-0.03
Sum Base Cations	-0.24
ANC	-0.31
Color	-0.21
SO_4	0.06
SiO_2	-0.13
Total P	-0.15

* Correlation coefficient significant at $\alpha=0.05$, adjusted for 14 tests, $p \leq 0.0036$.
Key: SO_4 = sulfate; SiO_2 = silica

3.3 INITIAL LAKE RECONNAISSANCE

Prior to initiating field sampling activities, a reconnaissance of the lake was conducted to select sites for deployment of fish sampling gear. Shoreline maps were prepared identifying the approximate extent and location of various features and habitat types in the lake littoral zone. Habitat types were defined based on the following characteristics: water depth; slope of the lake bottom; abundance and type of aquatic vegetation (emergent, submergent, floating); location of permanent inlets, outlets, shoals, or other physical features (docks, woody debris, beaver dams, etc.); DO; and temperature (see Section 3.4). These maps were not intended as an accurate depiction of littoral zone features, but as an aid for selecting specific sites for sampling. Bathymetric maps for the lake were also referenced, if available.

Appropriate sampling sites for fish were designated by the field crew leader and identified on the shoreline map. Sites selected were dispersed around the lake and included the following: a range of water depths and bottom slopes (e.g., shallow regions with a wide littoral zone and steeper shorelines and littoral zones); regions near major inlets; regions in the immediate vicinity of the lake outlet(s); sheltered bays and open promontories; and regions with different types of shoreline vegetation (e.g., coniferous forests, deciduous forests, marshes). More specific guidelines for selecting sampling sites were provided in the Fisheries Field Training and Operations Manual (Fabrizio and Taylor 1987). The objective was to sample the full diversity of lake habitats in order to collect as many fish species as possible within the limitations of the sampling gear.

3.4 IN SITU MEASUREMENTS

In situ measurements were taken at the ELS-I sampling site over the deepest part of the lake (Linthurst et al. 1986, Landers et al. 1988). In situ measurements consisted of Hydrolab determinations of water temperature, DO, pH, and specific conductance and determinations of Secchi transparency, air temperature, and site depth (Hagley et al. 1987). The Hydrolab was calibrated each morning prior to sampling, a field quality control check (QCC) was performed after arrival at the lake, and a final QCC was completed at the end of the day at the base site. Measurements with the Hydrolab were made first at 1.5 m below the water surface, then at 1.5 m above the lake bottom. If the temperature difference between these two depths was greater than 4 °C, the lake was considered stratified and a full vertical profile of measurements was conducted. Profile measurements were taken at 1-m intervals from 2.5 m to 10.5 m below the surface and at 2-m intervals from 10.5 m to 1.5 m above the lake bottom.

Depth graphs of temperature and DO were provided to the field crew leader to assist in selecting fish sampling locations. Hypoxic layers (with DO < 4 mg/L) were not fished. If a lake was determined to be thermally stratified, fish sampling sites were selected to include the thermocline and the upper hypolimnion.

3.5 COLLECTION OF WATER AND SEDIMENT SAMPLES

A routine water sample included two 60-mL polyethylene syringes (collected without exposure to air) for pH and Al analyses and one 500-mL polyethylene bottle for DOC, F, metals, and elements analyzed by inductively coupled plasma mass spectrometry. Additionally, water and sediment samples were collected in 2.5-L glass bottles and 60-mL Teflon jars, respectively, for mercury analyses (EPA, in prep.). Water samples were collected with a 6.2-L Van Dorn bottle at 1.5 m.

After water samples were collected, they were capped and stored in a cooler with frozen gel packs. Sediment samples for mercury analysis were placed in a separate cooler with frozen gel packs. The two syringe samples and the 500-mL aliquot of lake water were shipped from the base station to the Las Vegas processing laboratory within 24 hours from the time of collection.

3.6 FISH SURVEYS

3.6.1 Sampling Gear and Effort

Fish communities were sampled with four gear types: experimental gill net, modified Indiana trap net, beach seine, and hook and line (angling). Experimental gill nets consisted of five panels, each 7.6 m (25 ft) long and 1.8 m (6 ft) deep, of variable-dimension, monofilament nylon (25-, 38-, 51-, 64-, and 76-mm stretch mesh). Trap nets consisted of a 1.8 m by 0.9 m (6 ft by 3 ft) front box (19-mm stretch mesh) with two 6-m (20-ft) wings and a 15.2-m (50-ft) leader. Beach seines were 1.2 m (4 ft) deep and 7.6 m (25 ft) long of 4.8-mm woven mesh nylon. Angling was employed as a supplemental sampling procedure focusing on larger game fish, to be used for analysis of fish mercury content (EPA, in prep.). Detailed procedures and protocols for gear deployment and retrieval are outlined in the Fisheries Field Training and Operations Manual (Fabrizio and Taylor 1987).

With the exception of angling, the number of units of gear deployed varied as a function of lake area (Tables 3.1 and 3.3). Deviations from the proposed standard sampling effort occurred in some instances due to sampling problems or constraints imposed by the Michigan Department of Natural Resources or private owners. The sampling effort applied was lower than proposed in one lake each for gill nets, trap nets, and angling (Lakes 2B2-098, 2B2-100, and 2B1-039, respectively) (Table 3.1). Use of beach seines was limited by the availability of suitable shoreline areas for effective seining (i.e., shallow littoral areas without major obstructions or snags). Eleven of the 49 ELS-II lakes (22.4%) were not sampled with beach seines during the June-August survey (Table 3.1).

Table 3.3. Standard Fish Sampling Effort Per Lake

Lake Area (ha)	Experimental Gill Nets (number of overnight sets)	Trap Nets (number of overnight sets)	Beach Seines (number of 20-m hauls)	Angling (h)
<20	3	3	4	2
20-29	4	4	5	2
30-39	5	5	5	2
40-59	6	6	6	2
60-79	7	7	7	2
≥80	8	8	8	2

Gill nets and trap nets were set in the afternoon and retrieved the next morning, with one exception. In Bone Lake (2B3-023), the Michigan Department of Natural Resources requested that gill nets be set only during the day, for one day (10-13 hours per net). Nets were set for periods ranging between 10 and 29 hours, although, in most cases (87%), overnight sets lasted between 18 and 24 hours. In general, trap nets were deployed and retrieved before gill nets. Nets were tended in the same order in which they were set.

Seining and angling were conducted on the first day, usually in the afternoon. One unit of effort for the beach seine refers to one seine haul along approximately 20 m of shoreline. Each unit of effort was applied at a different sampling location. Angling effort involved two hours of hook and line fishing (one hour per each of two crew members) using Mr. Twister spinner bait lures cast from a boat at various locations around the lake. The time of day varied depending on the crew's schedule at the lake.

3.6.2 Field Measurements and Samples

Most fish collected were identified to species in the field. Specimens of questionable identity (e.g., apparent hybrids, uncommon species with limited distributions) or in taxonomically difficult groups (e.g., minnows, shiners) were preserved and returned to the base station for identification. These specimens were processed, identified, and coded to the lowest possible taxonomic level in the field, prior to preservation. The following references were used for fish identification: Scott and Crossman (1973), Eddy (1969), and Hubbs and Lagler (1947).

All individuals caught were counted by species. Partial specimens were handled by including all identifiable heads in the total count; pieces without heads and unidentifiable head segments were discarded. Numbers of fish caught were tallied by gear type, station (unit of sampling effort), and species on standard field data forms.

Game and index species were measured for length and weight and sampled for age estimation. The following were defined as game species:

walleye	Stizostedion vitreum
smallmouth bass	Micropterus dolomieui
largemouth bass	Micropterus salmoides
northern pike	Esox lucius
yellow perch	Perca flavescens
lake trout	Salvelinus namaycush
brook trout	Salvelinus fontinalis
rainbow trout	Oncorhynchus mykiss

Three species were defined as index species for mercury analyses:

yellow perch	Perca flavescens
white sucker	Catostomus commersoni
northern pike	Esox lucius

Other species were also measured for length and weight and sampled for age estimation if time permitted.

Total length measurements were tallied in 25-mm length intervals, by species and sampling unit. Individual lengths and weights were recorded and samples collected for age estimation for five fish (if available) per 25-mm length class per species. Fish were weighed using a spring balance (for individual or groups of fish > 0.5 kg) or portable electronic balance (for fish < 0.5 kg). Balances were zeroed prior to each use and checked for accuracy using a known weight at the beginning and end of each day and after every 30 fish. Weekly calibration checks were conducted with a series of known weights. Fish weight was recorded to the nearest 2 g for the spring scale and 1 g for the electronic balance; fish length was recorded to the nearest millimeter. Ten percent of the specimens (by species) were re-measured and re-weighed by a different crew member for estimates of precision (Section 4.2.1). Specimens re-weighed were not necessarily the same as those re-measured for length.

Scales, cleithra, or pectoral fin rays were collected to estimate fish age depending on the species:

walleye	scale
smallmouth bass	scale
largemouth bass	scale
northern pike	cleithrum
yellow perch	scale
lake trout	scale
brook trout	scale
rainbow trout	scale
white sucker	pectoral fin ray

Results from these analyses are presented in the report on fish mercury content (EPA, in prep.)

Selected specimens were preserved as a reference sample for the survey, including a set of representative specimens (up to three per species) for each species collected and any unidentified specimens or species of questionable identity. Species identifications were confirmed by Dr. L. Greenberg, ichthyologist, Michigan State University. No fish with obvious abnormalities were collected. Also, no species recognized by state agencies in Michigan and Wisconsin as rare, threatened, or endangered were encountered.

4. QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) procedures were implemented for all aspects of the ELS-II survey of fish community status in Subregion 2B. Major components of the QA/QC program were as follows:

- audits of field crews by supervisory personnel from Lockheed and Michigan State University to ensure compliance with the specified sampling protocol;
- a field and laboratory QA/QC program for all chemical analyses, including field and laboratory audit samples, field blanks, and field replicates;
- replicate measurements of fish length and weight and analyses for fish age estimation;
- duplicate sampling of fish communities in 10 lakes to quantify fish sampling variability (through time across the sampling period and between the two field crews); and
- rigorous data base verification and validation procedures, similar to those used during ELS-I.

4.1 WATER CHEMISTRY

The measurement methods and QA objectives for precision, accuracy, and detectability for physicochemical parameters measured during the ELS-I and ELS-II are summarized in Tables 4.1 and 4.2, respectively. The QA/QC procedures and results for the ELS-I were described in detail in Linthurst et al. (1986) and Drousé et al. (1986). Results from the ELS-II QA/QC program are summarized in Tables 4.3 and 4.4; the ELS-II procedures and protocol are described in Appendix A (Volume II).

The overall within-batch (system) precision for the sampling, processing, transportation, and analysis process for samples collected on a given day (defined as a batch) was estimated for 16 field replicates: four samples from each of four lakes. A field replicate is an additional sample collected at the lake site by the same field crew immediately after the routine sample is collected. The precision data quality objective (DQO) of 10% (Table 4.2) was achieved, except when analyte concentrations were less than ten times the required detection limit (Table 4.3).

The between-batch precision was estimated from multiple analyses of one natural and three synthetic samples analyzed on different days, i.e., within different batches (Table 4.3). The between-batch precision (expressed as the relative standard deviation) was generally larger than the within-batch precision for most parameters. The DQOs apply only to within-batch precision.

Table 4.1. Quality Assurance Objectives for Precision, Accuracy, and Detectability, and Measurement Methods for Physicochemical Parameters Measured during ELS-I

Parameter[a]	Units	Required Detection Limits	Precision Relative Standard Deviation Upper Limit[b] (%)	Accuracy Maximum Absolute Bias (%)	Method
Al, Total	μg/L	0.5	10 (<10) 20 (≤10)	10/20	EPA Method 202.2 (AAS)(furnace)
Al, Total Extractable	μg/L	5	10 (>10) 20 (≤10)	10/20	Extraction with 8-hydroxyquinoline into MIBK followed by AAS (furnace)
Acidity (BNC)	μeq/L	5	10	10	Titration with Gran plot
Alkalinity (ANC)	μeq/L	5	10	10	Titration with Gran plot
Ca	mg/L	0.01	5	10	EPA Method 215.1 -AAS (flame)
Cl	mg/L	0.01	5	10	Ion chromatography
True Color	Color Units[c]	0	±5[d]	—	Hatch Model CO-1 color determination
DIC	mg/L	0.05	10	10	Instrumental (similar to DOC)
DOC	mg/L	0.1	5 (>5) 10 (≤5)	10	EPA Method 415.2
F, Total	μg/L	5	5	10	Ion selective electrode
Fe	mg/L	0.01	10	10	EPA Method 236.1 - AAS (flame)
K	mg/L	0.01	5	10	EPA Method 258.1 - AAS (flame)
Mg	mg/L	0.01	5	10	EPA Method 242.1 - AAS (flame)

(continued)

Table 4.1. Continued

Parameter[a]	Units	Required Detection Limits	Precision Relative Standard Deviation Upper Limit[b] (%)	Accuracy Maximum Absolute Bias (%)	Method
Mn	mg/L	0.01	10	10	EPA Method 243.1 - AAS (flame)
Na	mg/L	0.01	5	10	EPA Method 273.1 - AAS (flame)
NH_4	mg/L	0.01	5	10	EPA Method 350.1
NO_3	mg/L	0.005	10	10	Ion chromatography
pH, Field	pH units	—	±0.1[d]	±0.1[d]	pH electrode and meter
pH, Analytical Laboratory	pH units	—	±0.05[d]	±0.1[d]	pH electrode and meter
P, Total	µg/L	2	10 (>10) 20 (>10)	10/20	USGS Method I-4600-78 or Modified USGS method
SiO_2	mg/L	0.05	5	10	USGS Method I-2700-78
SiO_4	mg/L	0.05	5	10	Ion chromatography
Specific conductance	µS/cm	e	1	5	EPA Method 120.1
Turbidity	NTU	2	10	10	Monitek Model 21 nephelometer

[a] Dissolved ions and metals determined, except where noted.

[b] Unless otherwise noted, this is the relative standard deviation for concentrations above 10 times the required detection limits.

[c] APHA platinum-cobalt units.

[d] Absolute precision goal in terms of applicable units.

[e] Blank must be ≤ 0.09 µS/cm.

Key: AAS = atomic absorption spectroscopy; BNC = base neutralizing capacity; DIC = dissolved inorganic carbon; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; Na = sodium.

Table 4.2. Quality Assurance Objectives for Precision, Accuracy, and Detectability and Measurement Methods for Physicochemical Parameters Measured during ELS-II in Subregion 2B

Parameter	Units	Required Detection Limit	Precision Relative Standard Deviation Upper Limit[a] (%)	Accuracy Maximum Absolute Bias (%)	Method
Al, total monomeric[b]	µg/L	7	10 (>10) 20 (≤10)	10 (>10) 20(≤10)	Flow injection analysis
Al, non-labile monomeric[b]	µg/L	7	10 (>10) 20 (≤10)	10 (>10) 20 (≤10)	Flow injection analysis
DOC	mg/L	0.1	5 (>5) 10 (≤5)	10	EPA Method 415.2
F, total dissolved	µg/L	5	5	10	Ion Selective Electrode
Specific conductance	µS/cm	—	1	5	Hydrolab
pH, laboratory	pH units	—	±0.01[c]	±0.05[c]	pH electrode
pH, field	pH units	—	±0.1[c]	±0.1[c]	Hydrolab

[a] Unless otherwise noted, this is the relative standard deviation for concentrations above 10 times the required detection limit.

[b] Labile monomeric Al, an estimate of the inorganic Al fraction, is calculated as the difference between total monomeric Al and non-labile monomeric Al.

[c] Precision and accuracy in absolute units.

Table 4.3. Estimates of Precision for Physicochemical Parameters Measured during ELS-II

Lake ID or Sample Code	N	Mean	Standard Deviation	Relative Standard Deviation (%)	Type of Precision Estimate[a]
pH **Routine Data Range:** **4.45-8.74**					
2B1-048	4	4.42500	0.02082	0.47	WB
2B2-061	4	5.58750	0.02630	0.47	WB
2B2-079	4	6.30500	0.06758	1.07	WB
2B3-009	4	8.17000	0.00816	0.10	WB
FN10	11	5.10455	0.06743		BB
LS6	6	4.28167	0.06882		BB
LS7	6	6.24333	0.11396		BB
LS8	6	8.52000	0.19204		BB
Total Monomeric **Al (μg/L)** **Routine Data Range:** **124-207**					
2B1-048	4	205.75	1.328	0.65	WB
2B2-061	4	94.50	2.159	2.28	WB
2B2-079	4	14.52	1.756	12.09[b]	WB
2B3-009	4	24.85	6.648	26.75[b]	WB
FN10	11	133.91	4.059		BB
LS6	5	16.64	2.476		BB
LS7	6	117.90	4.785		BB
LS8	5	252.16	15.615		BB
Non-Labile Monomeric **Al (μg/L)** **Routine Data Range:** **8.2-76.4**					
2B1-048	4	13.925	1.2500	8.98	WB
2B2-061	4	74.375	2.5851	3.48	WB
2B2-079	4	17.850	1.3000	7.28	WB
2B3-009	4	17.225	3.2253	18.72[b]	WB
FN10	11	39.982	5.7616		BB
LS6	5	14.200	2.1012		BB
LS7	6	10.333	5.1329		BB
LS8	5	18.920	3.5181		BB

(continued)

Table 4.3. Continued

Lake ID or Sample Code	N	Mean	Standard Deviation	Relative Standard Deviation (%)	Type of Precision Estimate[a]
DOC (mg/L) Routine Data Range: 0.4-21.8					
2B1-048	4	0.325	0.05000	15.38[b]	WB
2B2-061	4	21.500	0.35590	1.66	WB
2B2-079	4	4.000	0.31623	7.91	WB
2B3-009	4	4.775	0.41932	8.78	WB
FN10	11	3.200	0.17889		BB
LS6	5	1.100	0.07071		BB
LS7	5	7.420	0.20494		BB
LS8	5	14.520	0.42071		BB
Total F (μg/L) Routine Data Range: 5-76					
2B1-048	4	13.750	0.9574	6.96	WB
2B2-061	4	18.750	2.6300	14.03[b]	WB
2B2-079	4	6.250	2.0616	32.99[b]	WB
2B3-009	4	46.250	1.2583	2.72	WB
FN10	11	66.273	4.2916		BB
LS6	5	8.600	2.5100		BB
LS7	6	38.000	3.2863		BB
LS8	5	72.800	6.9785		BB

[a] WB - Within Batch
BB - Between Batch

[b] Concentration of the replicates was less than 10 times the required detection limit.

Table 4.4. Estimate of Laboratory Accuracy Using Synthetic Audits

Parameter	Theoretical Value	Mean Value	Relative Difference (%)
Audit Type: LS6			
Total Monomeric Al (µg/L)	10.0	16.64	66.40
DOC (mg/L)	0.30	1.10	266.67
F (µg/L)	10.0	8.6	14.00
pH	4.50	4.282	4.85
Audit Type: LS7			
Total Monomeric Al (µg/L)	125.0	117.9	5.68
DOC (mg/L)	7.50	7.42	1.07
F (µg/L)	40.0	38.0	5.00
pH	6.50	6.243	3.95
Audit Type: LS8			
Total Monomeric Al (µg/L)	250.0	252.16	0.86
DOC (mg/L)	15.00	14.52	3.20
F (µg/L)	80.0	72.8	9.00
pH	8.50	8.520	0.23

Results from the synthetic audit samples also provide estimates of the measurement accuracy (A), calculated as the relative percent difference:

$$A = \left| \frac{\overline{X} - T}{T} \right| * 100$$

where:

$\bar{X}$ = the mean measured concentration for the audit sample, and

T = the theoretical value for the audit sample.

At concentrations near the detection limit (e.g., audit sample LS6), the values for relative percent difference for total monomeric Al, DOC, and total F were quite high (14-267%) (Table 4.4). For audit samples at middle to high concentrations, on the other hand, the absolute bias was below 10% for all parameters, indicating a reasonable level of accuracy within the DQOs (Table 4.2). The accuracy of measurements of non-labile monomeric Al could not be assessed, since the theoretical levels of non-labile monomeric Al in the audit samples were not known.

4.2 FISH SURVEYS

4.2.1 Field Measurements

Duplicate measurements of fish length and weight were conducted on a random 10% sample of fish. Differences in length measurements averaged 1.4 mm (standard deviation = 1.7 mm). Weight measures differed by an average of 2.1 g (standard deviation = 5.4 g). In most cases (72%), differences in length and weight between the duplicate measurements were < 1% of the mean, indicating a high level of precision for both measurements.

4.2.2 Duplicate Fish Surveys

In order to obtain an estimate of sampling variability, 10 of the 49 lakes were sampled twice over the three-month sampling period. All 49 lakes were sampled initially (standard sample) between 8 June and 30 August 1987. Resampling of the 10 lakes for QA/QC occurred between 31 August and 12 September. In general, the two surveys per lake were conducted by different field crews. Differences in results from the duplicate surveys reflect, therefore, the combined effect of several major sources of variation, including the sampling error for the ELS-II survey protocol, any trends through time in fish catchability, and crew-to-crew differences in sampling effectiveness. Given the effort required to complete a comprehensive fish survey per lake, it was not possible to conduct sufficient sampling to separately quantify the individual components of the total error term.

Several factors were considered in selecting lakes for resampling, including (1) the need for additional fish of certain species for mercury analysis, (2) the time of the first sample, and (3) the catch in the first sample (including lakes with few or no fish as well as lakes with relatively large numbers of fish caught). Thus, the 10 lakes were not selected at random, but were chosen based on examination of results from the initial fish survey.

Four major types of data were collected on fish communities in lakes in Subregion 2B:

1. species richness, i.e., the total number of fish species caught per lake;
2. presence/absence of individual fish species, estimated from the presence or absence of the species in the catch (catch/no catch);

3. relative fish abundance, estimated from the total number of fish caught (by species) or the catch per unit of sampling effort [catch per unit effort (CPUE)]; and
4. fish size and condition, based on measurements of fish length and weight.

Results from the duplicate surveys of the 10 QA/QC lakes are discussed below for each of these indices of fish community status.

Measures of species richness were not significantly different ($p > 0.05$) for the two sample periods, based on a Wilcoxon signed rank test (Hollander and Wolfe 1973). Equal values were recorded for 7 of the 10 lakes, while in 3 lakes species richness measured in the initial sample exceeded species richness in the second sample by one to two species (Table 4.5). In addition, measures of species richness in all 49 lakes were not significantly correlated ($p > 0.05$) with either sampling sequence (date) or the total number of fish caught per lake, based on a Spearman's rank correlation (Hollander and Wolfe 1973).

Czekanowski's similarity coefficient (S_c) (Bray and Curtis 1957) was calculated as a measure of the similarity in species composition in the two samples per lake (Table 4.5):

$$S_c = \frac{2\left(X_{jk}\right)}{X_j + X_k}$$

where:

X_j = the number of species in the first sample,

X_k = the number of species in the second sample, and

X_{jk} = the number of species common to both samples.

One lake had no fish caught in either survey (S_c undefined). Five lakes had exactly the same complement of species caught in both surveys ($S_c = 1.0$), and one additional lake had $S_c = 0.91$, indicating a high degree of similarity. Of the three remaining lakes, two had $S_c = 0.67$, while one had $S_c = 0$ (Lake 2B2-078, with one fish species caught during the initial survey but no fish caught in the duplicate sample). The types of fish species present in one but not both samples varied for each lake.

The Fisher exact test (Fleiss 1981) was used to evaluate potential trends in the presence/absence (catch/no catch) data by species. Four species occurred in a sufficient number of the 10 QA/QC lakes for calculation of a valid chi-square test: yellow perch, largemouth bass, northern pike, and bluegill sunfish. In each case, the proportion of lakes containing the species did not vary significantly ($p > 0.05$) between the duplicate surveys.

Table 4.5. **Summary of Results for Species Richness from Duplicate Surveys of Ten Lakes**

Lake ID	Sample Dates	Species Richness	Coefficient of Variation[a]	Similarity Coefficient[b]
2B1-022	25 Jun 1 Sep	4 2	47.1	0.67
2B1-038	21 Aug 11 Sep	0 0	-	-
2B2-049	30 Jun 9 Sep	1 1	0	1.0
2B2-074	24 Jun 2 Sep	3 3	0	1.0
2B2-075	27 Jun 1 Sep	4 4	0	1.0
2B2-078	14 Jul 3 Sep	1 0	141.4	0
2B2-100	3 Jul 9 Sep	1 1	0	1.0
2B3-037	29 Jul 12 Sep	11 11	0	0.91
2B3-057	8 Jul 4 Sep	7 5	23.6	0.67
2B3-058	10 Jul 3 Sep	1 1	0	1.0

[a] Coefficent of variation calculated as the standard deviation divided by the mean for the duplicate samples, assuming a normally distributed within-lake variance.

[b] Czekanowski's similarity coefficient defined as two times the number of species common to both samples divided by the sum of the number of fish species caught in the first sample plus the number caught in the second sample.

All of the above analyses indicate that the sampling errors associated with measuring species richness and fish species presence/absence in the ELS-II were relatively minor and are not likely to measurably bias comparisons of fish community status among lakes.

Results from the duplicate samples for total fish catch and CPUE are summarized in Table 4.6. Given the high degree of variability in fish catch rates for angling and beach seines, only fish collected using gill nets and trap nets are included in these analyses. CPUE is calculated as the mean per net per hour fished. Coefficients of variation for CPUE calculated per hour per net tended to be equal to or less than the coefficients of variation for CPUE calculated on a per net (per overnight set) basis.

Table 4.6. **Summary of Results for Fish Catch (All Species Combined) for the Duplicate Surveys of Ten Lakes**

				CPUE (fish/h/net)			
		Total Catch[a]		Gill Net		Trap Net	
Lake ID	Sample Dates	Mean	Coefficient of Variation (%)	Mean	Coefficient of Variation (%)	Mean	Coefficient of Variation (%)
2B1-022	25 Jun	28	51.4	0.13	45.2	0.27	80.1
	1 Sep	60		0.07		0.98	
2B1-038	21 Aug	0	-	0	-	0	-
	11 Sep	0		0		0	
2B2-049	30 Jun	792	27.0	10.45	53.3	1.26	70.8
	9 Sep	538		4.73		3.80	
2B2-074	24 Jun	3000	87.5	0.50	44.5	67.23	100.5
	2 Sep	706		0.97		11.38	
2B2-075	27 Jun	129	21.5	0.83	42.5	1.12	23.1
	1 Sep	95		0.44		1.56	
2B2-078	14 Jul	1	141.4	0	-	0.01	141.4
	3 Sep	0		0		0	
2B2-100	3 Jul	204[a]	15.2	2.47	64.4	1.49	47.1
	9 Sep	253		0.93		2.98	
2B2-037	29 Jul	238	72.3	1.29	13.7	2.28	98.8
	12 Sep	77		1.06		0.40	
2B3-057	8 Jul	97	105.7	0.37	57.7	1.33	111.9
	4 Sep	14		0.16		0.16	
2B3-058	10 Jul	2403	43.7	4.91	10.0	27.52	57.2
	3 Sep	4555		4.26		64.85	

[a] Total catch based on gill and trap nets only. All lakes were fished with three gill nets and three trap nets each date. However, in the 3 July sample for lake 2B2-100, fish were lost from one of the three trap nets and thus could not be included in the value for total catch.

Values for total catch and CPUE in trap nets and gill nets were not significantly different ($p > 0.05$) between the two sample dates, based on the Wilcoxon signed rank test. In addition, no significant trend in fish catch over time was detected for the 49-lake data set ($p > 0.05$, Spearman's rank correlation).

The coefficient of variation for the duplicate measures of catch ranged between 15.2% and 141.4% for total catch, 9.5% and 141.4% for trap-net CPUE, and 10.0% and 64.4% for gill-net CPUE. In six of eight lakes with fish caught in both surveys in both gear types, the variance in CPUE (and coefficient of variation) for trap nets exceeded that for gill nets. The variability in fish catch (and CPUE) was also generally higher in lakes with more fish caught (Figure 4-1).

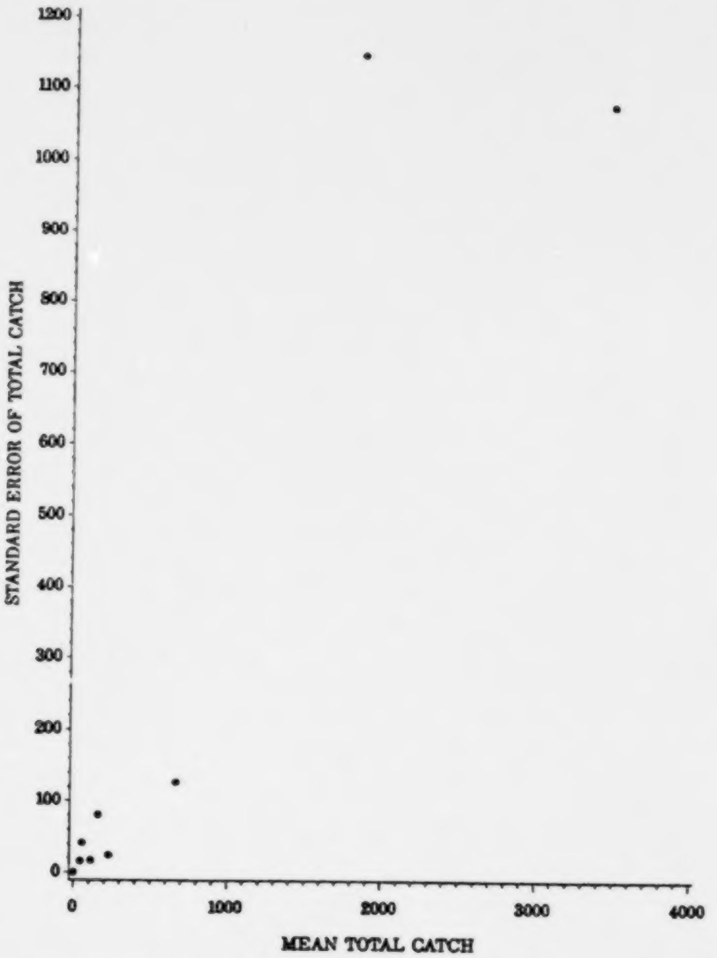

Figure 4-1. **Standard error for the duplicate measures of total catch, as a function of the mean catch per lake.**

Assuming a constant capture (sampling) efficiency (q), the numbers of fish caught (C) per unit sampling effort (f) (i.e., the CPUE) should be directly proportional to fish abundance in the lake (N):

$$C = q \cdot f \cdot N$$

A large number of factors, however, influence fish capture efficiency, many of which cannot be controlled by simply standardizing sampling methods, season, effort, and location. As a result, for a constant N, the variability in CPUE is typically quite high, making detection of patterns among lakes, or over time in a given lake, difficult (Ricker 1975, Bannerot and Austin 1983). The variability in catch and CPUE observed for the ELS-II data is not atypical of that observed in most fisheries data sets. Although the data are limited (only 10 lakes with duplicate samples), there is no indication of bias or trends in capture efficiency that might result in misinterpretation of the survey results.

Four lakes had a sufficient number of a given species caught and measured to compare estimates of fish size and condition factors from the duplicate surveys (Table 4.7): yellow perch in lake 2B2-049; yellow perch in lake 2B2-100; yellow perch and largemouth bass in lake 2B2-075; and yellow perch, largemouth bass, white sucker, and northern pike in lake 2B3-037. Differences in fish length, weight, and condition in the duplicate samples (paired by species, by lake) were not significant ($p > 0.05$, Wilcoxon signed rank test).

Table 4.7. Comparison of Fish Length, Weight, and Condition Factors for the Duplicate Surveys of Ten Lakes

				Total Length (mm)		Weight (g)		Condition Factor[a]	
Species	Lake ID	Sample Dates	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Yellow Perch	2B2-049	30 Jun	44	138.6	24.8	29.7	15.0	1.03	0.08
		9 Sep	37	148.6	46.3	44.9	52.6	1.01	0.10
	2B2-075	27 Jun	32	124.7	17.3	19.9	13.0	0.95	0.06
		1 Sep	14	153.8	46.7	44.6	41.1	0.90	0.12
	2B2-100	3 Jul	42	159.0	26.1	43.6	19.3	1.02	0.08
		9 Sep	39	155.1	27.4	41.3	21.8	1.00	0.09
	2B3-037	29 Jul	43	128.6	33.0	25.8	29.5	0.97	0.10
		12 Sep	20	117.3	6.1	14.8	2.2	0.91	0.06
Largemouth Bass	2B2-075	27 Jun	7	250.6	60.9	240.7	156.8	1.31	0.12
		1 Sep	9	143.1	114.3	133.0	264.7	1.24	0.14
	2B3-037	29 Jul	6	103.8	25.4	15.0	13.4	1.15	0.17
		12 Sep	5	197.2	146.8	360.8	706.0	1.35	0.28
White Sucker	2B3-037	29 Jul	12	306.9	82.7	334.3	217.8	1.04	0.19
		12 Sep	11	284.6	70.1	299.0	217.6	1.09	0.07
Northern Pike	2B3-037	29 Jul	7	632.0	75.0	1462.9	485.7	0.56	0.06
		12 Sep	9	651.7	120.3	1675.2	1278.4	0.55	0.10

[a] Assuming isometric growth, the condition factor = $(\text{weight}*10^5)/(\text{total length})^3$ (Anderson and Gutreuter 1983)

5. LAKE PHYSICAL CHARACTERISTICS

Lakes in the Upper Peninsula of Michigan (Subregion 2B) were among the smallest (median area = 11 ha) and shallowest (median depth = 2.9 m) of any subregion sampled during the ELS-I (Linthurst et al. 1986, Eilers et al. 1988). Since very shallow lakes, considered unlikely to support a significant fishery, were excluded from the ELS-II studies in Subregion 2B (see Section 2.2.1), ELS-II median depths were somewhat greater than ELS-I medians. Median values for lake depth for the ELS-II target population and for lakes sampled during ELS-II were 6.1 and 4.3 m, respectively (Table 5.1). The exclusion of shallow lakes from the ELS-II extended to both small and large lakes, however, so lake areas from ELS-I to ELS-II remained fairly similar: median values of 11 ha for the ELS-I target population, 13 ha for the ELS-II target population, and 9 ha for lakes sampled during ELS-II (Table 5.1). Lake area and lake depth (as estimated by the ELS-I site depth) were not significantly correlated ($p > 0.05$, Spearman's rank correlation) in the ELS-I data set for Subregion 2B.

Table 5.1. Physical Characteristics of Lakes in Subregion 2B, for the ELS-I Target Population ($\hat{N}$=1050), ELS-II Target Population ($\hat{N}$=597), and the 49 Lakes Sampled During ELS-II

	ELS-I Target Population		ELS-II Target Population		Lakes Sampled in ELS-II	
Variable	Median	Range	Median	Range	Median	Range
Lake Area (ha)	11	4-578	13	4-262	9	4-262
Site Depth (m)	2.9	0.9-21.9	6.1	1.5-20.4	4.3	1.5-20.1
Elevation (m)	267	184-558	289	220-558	282	20-546
Watershed Area (ha)	115	10-54,501	91	10-54,501	60	10-54,501
Watershed-to-Lake Area Ratio	10.2	2.4-1703.2	7.0	2.4-1703.2	7.0	2.4-1703.2
Secchi Depth (m)	1.5	0.4-7.6	2.1	0.8-7.6	2.2	0.8-7.6

The majority of lakes in Subregion 2B occur at moderate elevation; median values for the ELS-I target population, ELS-II target population, and lakes sampled in ELS-II were 267, 289, and 282 m, respectively (Table 5.1). Over 75% of the lakes in each group occur at elevations below 450 m. No significant correlation was found for either lake elevation to lake area or for lake elevation to lake depth ($p > 0.05$, Spearman's rank correlation) in the ELS-I data set for Subregion 2B.

Watershed area and the watershed-to-lake area ratio provide a first-order index of the water residence time (or flushing rate) for the lake. Median values for the watershed-to-lake area ratio were 10.2 in the ELS-I target population, and 7.0 in both the ELS-II target population and the ELS-II sample (Table 5.1).

Four lake types were defined for the ELS-I:

1. drainage lakes — lakes with surface water outlets or with both inlets and outlets;
2. reservoirs — artificial lakes as indicated by a dam at the lake outlet;
3. seepage lakes — lakes with no permanent surface water inlets or outlets; and
4. closed lakes — lakes with a surface water inlet but no surface water outlet.

The majority of lakes in Subregion 2B (51% of the ELS-I target population) are drainage lakes. Seepage lakes are also quite common, however, comprising an estimated 37.7% of the ELS-I target population and 39.8% of the ELS-II target population. Twenty-nine of the 49 lakes sampled during the ELS-II (59.2%) were seepage lakes. Comparisons of the physical characteristics (lake area, depth, and elevation) of seepage versus nonseepage lakes for the 49 ELS-II lakes using non-parametric Wilcoxon rank sum and Kolmogorov-Smirnov tests (Hollander and Wolfe 1973) indicate no significant differences ($p > 0.05$) between the two lake groups.

During the ELS-II, *in situ* measurements of temperature and DO were taken at 1.5 m below the lake surface and at 1.5 m above the lake bottom. If the temperature difference between these two depths exceeded 4 °C, the lake was considered thermally stratified and additional profile data on temperature and DO were collected (Section 3.4). Lakes in the ELS-II were sampled over a three-month period from early June through the end of August. Thus, changes in the temperature and DO profile over this sampling period may hinder among-lake comparisons.

Of the 49 lakes sampled during ELS-II, 24 (49.0%) were classified as thermally stratified. Forty-one percent (n=20) of the lakes sampled had DO levels < 4 mg/L at one or more depths in the water column. Thermally stratified lakes had significantly ($p \leq 0.05$) lower minimum values for DO and a higher percentage of the water column with DO < 4 mg/L (based on Wilcoxon rank sum and Kolmogorov-Smirnov tests). In addition, thermally stratified lakes were generally deeper ($p \leq 0.05$) than nonstratified lakes.

Measures of Secchi depth, an index of lake transparency, were taken during both ELS-I (in fall 1984) and ELS-II (in summer 1987). The ELS-I and ELS-II values for Secchi depth are significantly correlated ($r=0.80$), although some divergence between the two samples is evident (Figure 5-1). Twelve of the ELS-II lakes had a Secchi depth exceeding the lake depth (i.e., the Secchi disk was visible on the lake bottom) and are not included in Figure 5-1.

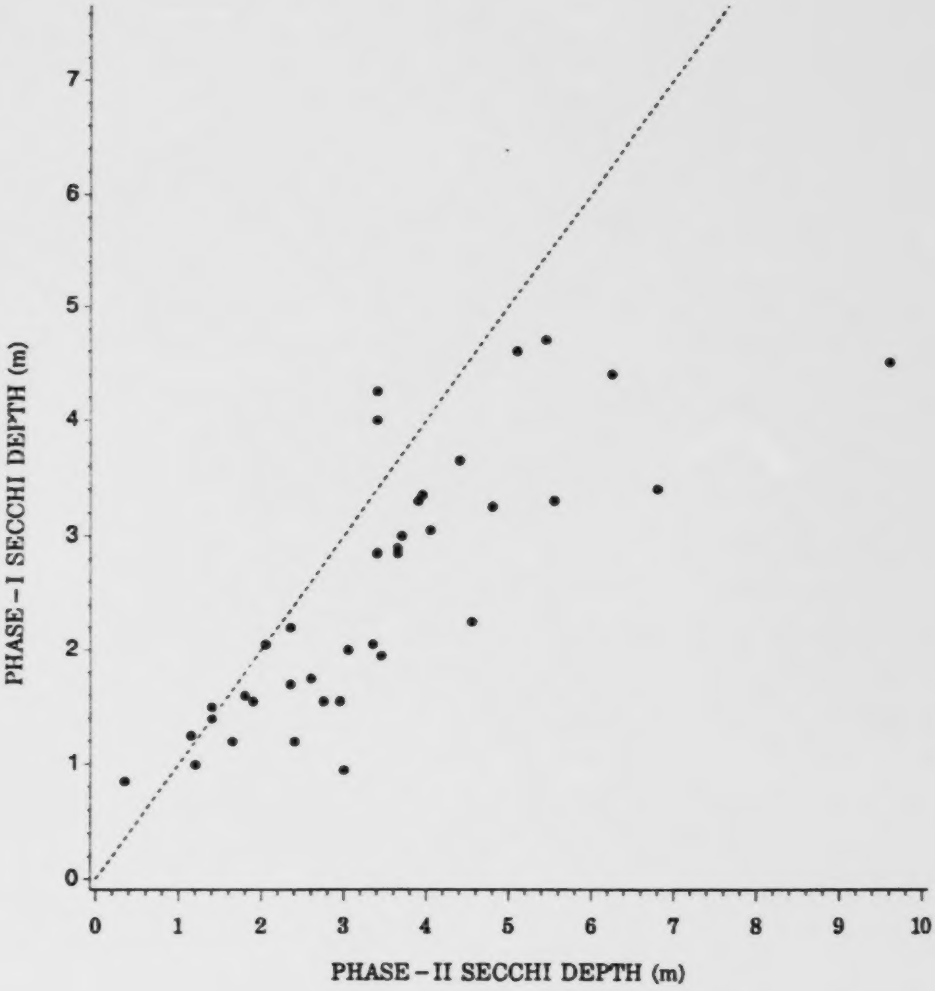

Figure 5-1. Comparison of ELS-I and ELS-II values for Secchi depth (m).

6. LAKE CHEMICAL CHARACTERISTICS

The primary objective of the ELS-I was to characterize the population of lakes expected to have low ANC in selected areas of the eastern United States. During the design phase of the ELS-I, it was recognized that the effects of both temporal and spatial variability in lake chemistry could compromise the survey results. The within-lake variability had to be minimized in order to observe differences among lakes. An attempt was made to overcome the effects of temporal and spatial variability through the use of the "index" concept. The index concept rests on two major assumptions: (1) that the chemical characteristics of a lake can be related to other lakes by sampling at a time when within-lake variability is minimized and (2) that the index sample is representative of within-lake chemistry and can be related to chemical conditions in the lake in other locations and at other times of the year.

During the ELS-I, a single water sample was collected at 1.5 m depth over the deepest part of the lake during fall overturn (i.e., the fall period when lakes were well mixed). A review of sampling seasons indicated that the fall mixing period would provide the most appropriate index period for sampling because of the low temporal and spatial variability in lake chemistry (Landers et al. 1988). It is obvious that one sample, at one location in the lake, at one time on one day, and at a specific season of a particular year is incapable of characterizing the complex chemical or biological dynamics of the sample lake. However, the purpose of the survey was to characterize geographical areas, not the dynamics of individual lakes. With this in mind, the chemical analysis for the fall 1984 sample provides a representative index of the lake chemistry that can be compared with the chemistry of other lakes sampled to detect regional patterns.

For the most part, the ELS-II data on fish communities in Subregion 2B that are reported in this document are interpreted relative to the ELS-I index of lake chemistry collected in fall 1984. Relatively few measurements of water chemistry were collected coincident with the ELS-II fish surveys in summer 1987, largely because of the high variability in lake chemistry expected to occur over the three-month sampling period (8 June to 30 August 1987). Since fish grow and live through a number of years, fish community status in 1987 would likely reflect both past and present-day physical and chemical conditions in the lake. Thus, the 1984 ELS-I measure of lake chemistry was selected as the best available index of the chemical conditions to which fish populations had been exposed. It is recognized that the ELS-I data are not direct measures of chemical conditions during those specific times and locales critical to fish population response, but it is assumed that the ELS-I index chemistry is at least correlated with these water quality values of interest.

6.1 ELS-I FALL INDEX SAMPLE

The chemical characteristics of the ELS-I and ELS-II target populations and the 49 lakes sampled during ELS-II in Subregion 2B, based on the ELS-I index sample, are summarized in Table 6.1. Lake-specific data for each of the 49 lakes sampled are presented in Appendix B.

Table 6.1. Chemical Characteristics of Lakes in Subregion 2B, for the ELS-I Target Population ($\hat{N}=1050$), ELS-II Target Population ($\hat{N}=597$), and the 49 Lakes Sampled During ELS-II

	ELS-I Target Population		ELS-II Target Population		Lakes Sampled in ELS-II	
Variable	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
ANC (μeq/L)	284	-49-2726	164	-48-2726	25	-48-2726
pH	7.10	4.43-8.58	6.93	4.43-8.25	5.75	4.43-8.25
Ca (μeq/L)	246	13-1826	179	22-1826	51	22-1826
Mg (μeq/L)	148	11-984	95	13-984	32	13-984
Na (μeq/L)	29	3-245	25	3-171	12	3-171
K (μeq/L	13	3-30	14	5-30	12	5-30
Sum Base Cations (μeq/L)	468	54-2966	282	54-2966	119	54-2966
Ext. Al (μg/L)	3	0-213	5	0-213	11	0-213
DOC (mg/L)	6.8	0.2-28.8	9	0.2-15.0	4.7	0.2-13.9
Color (PCU)	31	5-345	28	5-125	25	5-125
SO_4 (μeq/L)	78	16-281	77	16-161	67	17-161
SiO_2 (mg/L)	2.3	0.0-17.6	2.1	0.0-12.3	0.3	0.0-9.6
Total P (μg/L)	13	0-146	12	0-39	12	0-39

In ELS-I, Subregion 2B was estimated to have the highest percentage of acidic (11.3%) and low-pH lakes (9.4% with pH ≤ 5.0) in the Upper Midwest region (see Table 1.1). In addition, lakes selected for sampling for the ELS-II were specifically weighted to favor systems with low pH (Section 2.2.2). Forty-one percent (40.8%) of the lakes sampled were acidic, with ANC ≤ 0 μeq/L, and 24.5% had pH ≤ 5.0. Thus, the proportion of low ANC and low pH lakes among the 49 ELS-II lakes is distinctly higher than for either the ELS-I target population or the ELS-II target population (Figures 6-1a and b). As noted in Section 2.2.2, pH and Ca levels in lakes in the subregion are highly correlated (r=0.77, based on Spearman's rank correlation, p=0.0001). As a result, lakes sampled in the ELS-II also had generally lower Ca levels than either the ELS-I or ELS-II target populations (Figure 6-1c). Calcium concentrations for the 49 ELS-II lakes ranged between 22 and 1826 μeq/L (Table 6.1); 49.0% of the lakes had levels < 50 μeq/L (1.0 mg/L).

Subregion 2B also contains a relatively large population of high-ANC, high-pH lakes. Median values for the subregion (ELS-I target population) for ANC (284 μeq/L) and pH (7.10) are high relative to other subregions in the Upper Midwest (Linthurst et al. 1986). This heterogeneity in lake chemistry can be explained largely by the diversity of bedrock types and geology in the area (Rapp et al. 1987, Eilers et al. 1988). Five of the 49 lakes sampled in the ELS-II (10.2%) had ANC > 1000 μeq/L; nine (18.4%) had ANC > 500 μeq/L.

Acidic lakes in Subregion 2B are generally clear water, with a median color value of 22 PCU (ELS-I target population). Fifteen of the 20 acidic lakes sampled (75%) had color ≤ 25 PCU; 65% had DOC ≤ 4 mg/L. Higher pH lakes tend to have higher DOC (r=0.45 for the 49 ELS-II lakes; p=0.0011, Spearman's rank correlation analysis), although a high degree of scatter is evident in the relationship (Figure 2-3). Reflecting the weighted selection of low-pH lakes and the deletion of very shallow lakes (many of which had quite high DOC), the ELS-II sample and target population had a higher proportion of low DOC lakes relative to the ELS-I target population (Figure 6-1d).

As noted in Section 5, a high proportion of the lakes in Subregion 2B are seepage lakes (37.7% of the ELS-I target population, 39.8% of the ELS-II target population, and 59.2% of the lakes sampled in ELS-II). The chemical characteristics of seepage and nonseepage lakes are contrasted in Table 6.2 for the 49 ELS-II lakes. Levels of ANC, Ca, Mg, Na, sum of base cations, color, and SiO_2 were significantly lower (at $\alpha=0.05$, adjusted for 14 tests, $p \leq 0.0036$) in seepage lakes than in nonseepage lakes; differences in pH, K, DOC, and SO_4 occurred at $0.0036 < p \leq 0.05$. Sixteen of the 20 acidic lakes

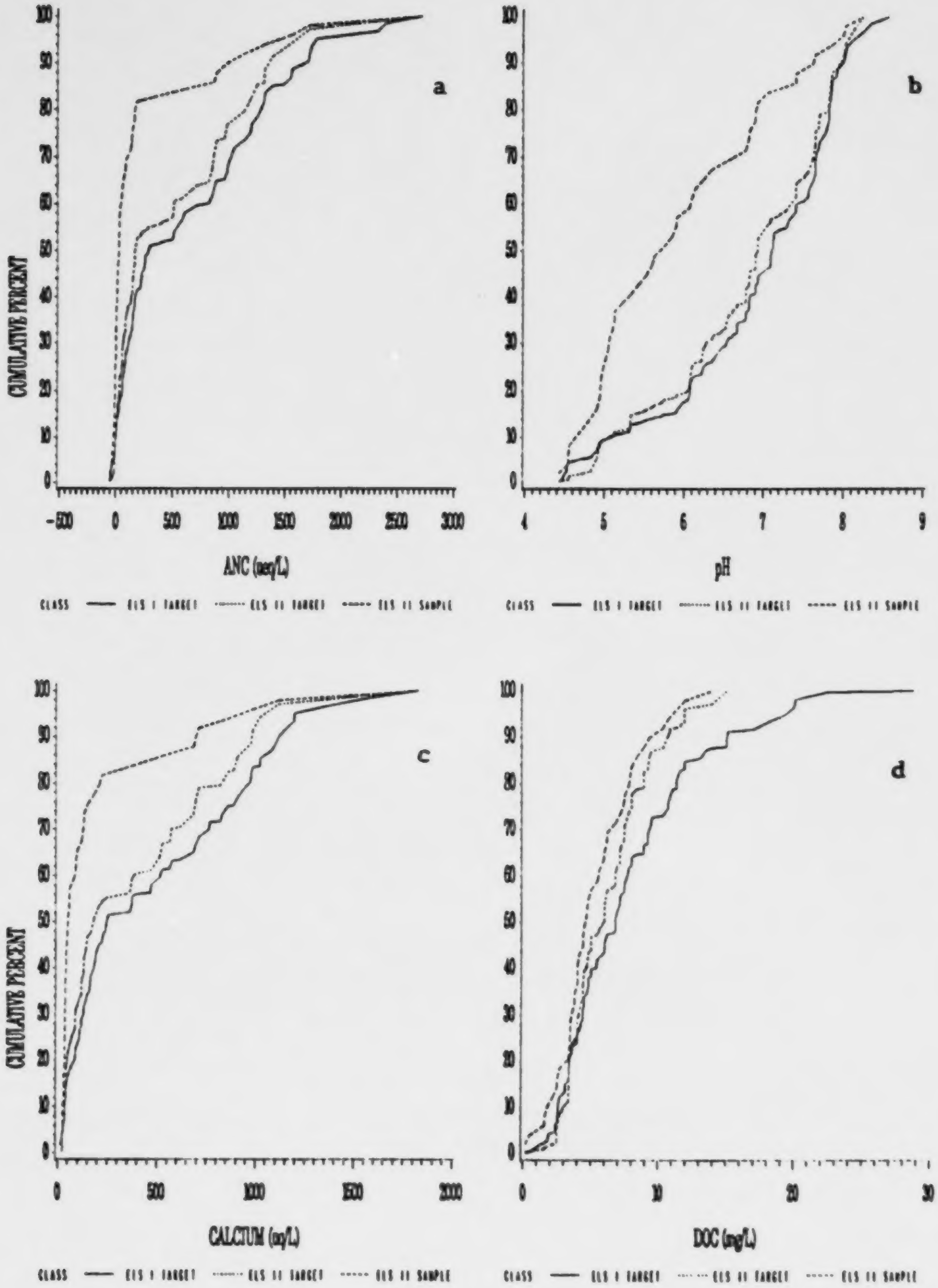

Figure 6-1. **Cumulative frequency distributions for the ELS-I target population, the ELS-II target population, and the 49 lakes sampled for (a) ANC, (b) pH, (c) Ca, and (d) DOC.**

Table 6.2. **Comparison of Lake Chemistry by Lake Type: Seepage Lakes versus Other Lake Types (Drainage, Reservoir, Closed) for the 49 Lakes Sampled During ELS-II**

Variable	Seepage Lakes		Other Lake Types		Test Statistics[a]	
	Median	Range	Median	Range	Wilcox.	K-S
pH	5.23	4.43-8.25	6.79	4.74-8.03	0.0052	0.0128
ANC (µeq/L)	-1	-46-1665	134	-20-2699	0.0014*	0.0227*
Inorg. Al (µg/L)	9	0-192	12	0-39	>0.05	>0.05
Ext. Al (µg/L)	11	0-213	10	0-120	>0.05	>0.05
Ca (µeq/L)	38	22-860	131	35-1826	0.0004*	0.0007*
Mg (µeq/L)	26	13-766	83	16-984	0.0005*	0.0004*
Na (µeq/L)	10	3-34	25	6-171	0.0002*	0.0004*
K (µeq/L)	10	5-21	14	5-30	0.0050	0.0074
Sum Base Cations (µeq/L)	88	50-1680	254	68-2960	0.0004*	0.0007*
DOC (mg/L)	4.0	0.2-10.3	6.5	2.5-13.9	0.0070	0.0264
Color (PCU)	21	5-80	37	10-125	0.0017*	0.0237
SO_4 (µeq/L)	60	17-144	85	48-161	0.0101	>0.05
SiO_2 (mg/L)	0.1	0-3.2	2.2	0.2-9.6	0.0001*	0.0001*
Total P (µg/L)	11	0-39	13	1-35	>0.05	>0.05

[a] Calculated p values for non-parametric comparisons of seepage lakes versus other lake types using the Wilcoxon rank sum (Wilcox.) and Kolmogorov-Smirnov (K-S) tests. Asterisks indicate statistical significance at $\alpha=0.05$ adjusted for 14 tests, i.e., $p \leq 0.0036$.

sampled (80%) were seepage lakes. The high proportion of seepage lakes in the ELS-II sample is evident in the distinctly lower median value for SiO_2 in the 49 sample lakes than in either the ELS-I or ELS-II target populations (Table 6.1).

Concentrations of extractable (total monomeric) Al measured in ELS-I were generally quite low. An estimated 80% of the ELS-I target population had ≤ 12 µg/L (Eilers et al. 1988). Values for the 49 ELS-II lakes ranged between 0 and 213 µg/L (Table 6.1), although 85.7% of the lakes sampled had extractable Al levels ≤ 50 µg/L.

Sulfate levels in Subregion 2B (median value 78 µeq/L for the ELS-I target population) were slightly higher than for other subregions in the Upper Midwest (regional median 57 µeq/L), although lower than levels in lakes in the northeastern United States (regional median 115 µeq/L) (Linthurst et al. 1986, Eilers et al. 1988). Concentrations for the 49 ELS-II lakes ranged between 17 and 161 µeq/L, with a median value of 67. Sulfate concentrations in the 49 lakes sampled were similar to, although slightly lower than, values for the ELS-I and ELS-II target populations (Table 6.1).

6.2 COMPARISON OF 1984 FALL INDEX WITH 1987 SUMMER CHEMISTRY

Water samples collected during the ELS-II surveys of fish communities in summer 1987 were analyzed for pH, total pyrocatechol violet (PCV) reactive Al, organic PCV reactive Al, and total F (Sections 3.5 and 4.1). In addition, pH, conductivity, temperature, and DO were measured in situ (Section 3.4). Lake-specific data for each of the 49 ELS-II lakes are presented in Appendix B. Other samples were also collected to assess concentrations of mercury and other trace metals in water and sediment; these data are discussed in a separate report evaluating mercury bioaccumulation (EPA, in prep.).

Measured values of pH and conductivity for fall 1984 (ELS-I) and summer 1987 (ELS-II) for the 49 ELS-II lakes in Subregion 2B are compared in Figure 6-2. Results for the two sampling periods were similar, with no dramatic differences for either variable between the sampling dates. Of the variables measured in both 1984 and 1987 (pH, conductivity, fluoride, and temperature), only temperature differed markedly between the two samples. As expected, temperatures measured at 1.5-m depth during summer (1987) were 5 °C to 22 °C warmer than values measured in fall (1984). None of the 49 ELS-II lakes were thermally stratified during the fall 1984 sampling, while 24 of the 49 lakes were stratified when sampled in summer 1987.

As part of EPA's Long-Term Monitoring Program, chemical conditions in 25 lakes in the Upper Peninsula of Michigan and northcentral Wisconsin have been monitored seasonally (spring, summer, and fall) since fall 1983 (Newell et al. 1987). Data on ANC, pH, and Ca for these lakes collected between 30 October 1984 and 4 November 1987 are summarized in Table 6.3 to illustrate the approximate magnitude of within-lake seasonal and year-to-year variations in water chemistry. Variations in ANC of 30 to 50 µeq/L, pH of 0.2 to 0.6 pH units, and Ca of 30 to 60 µeq/L are not atypical. However, only one lake, Lake Nevins, exhibited a detectable trend in lake chemistry (decreasing ANC, pH, and Ca) over the three-year period.

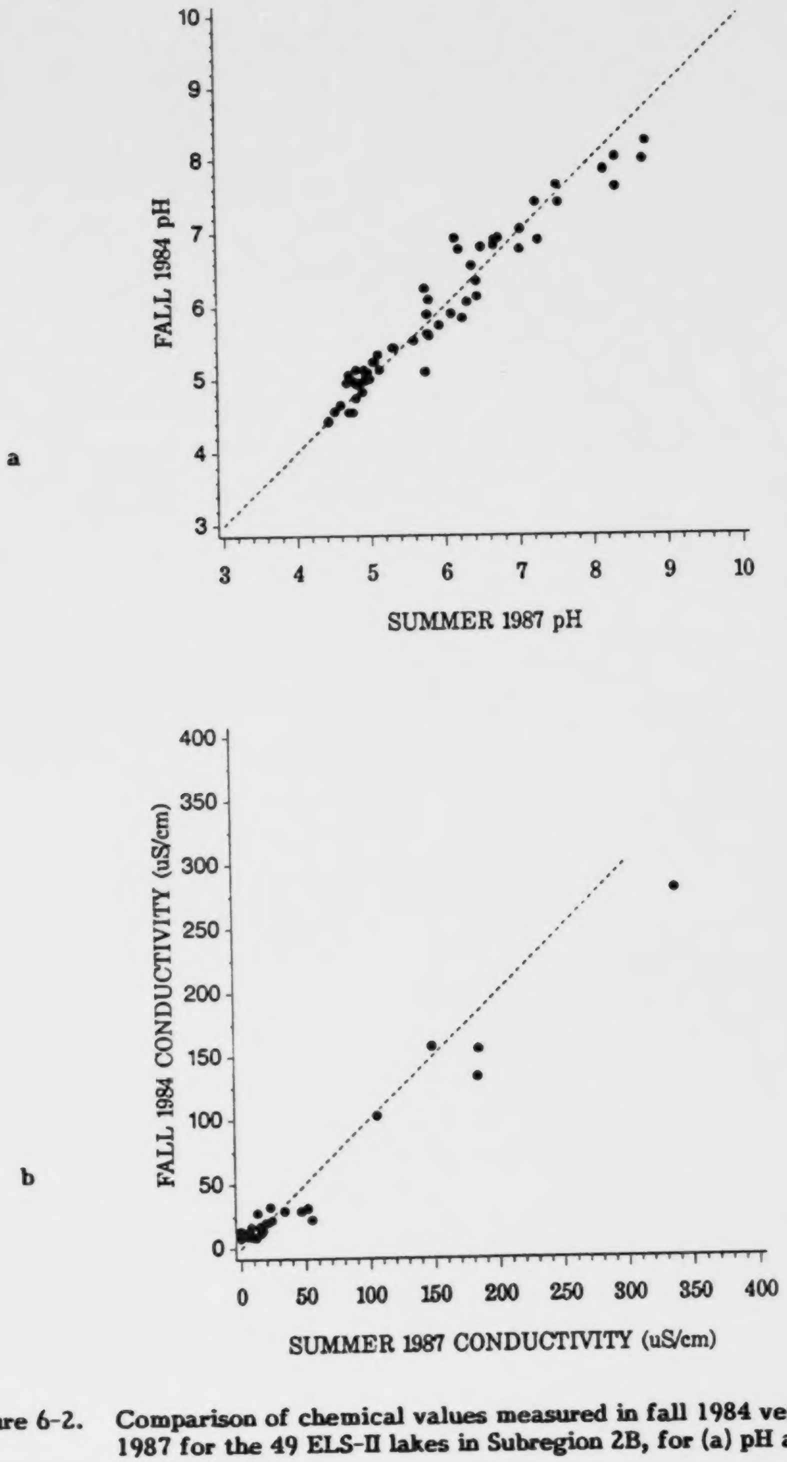

Figure 6-2. Comparison of chemical values measured in fall 1984 versus summer 1987 for the 49 ELS-II lakes in Subregion 2B, for (a) pH and (b) conductivity.

Table 6.3. Summary of Long-Term Monitoring Data for Acid Neutralizing Capacity (ANC), Calcium (Ca), and pH from Lakes Located in the Upper Peninsula of Michigan and North Central Wisconsin

		ANC (μeq/L)		Ca (μeq/L)		pH	
Lake Name	**N**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
Johnson	9	-18	30	58	25	4.7	0.4
McNearney	9	-35	46	61	39	4.4	0.2
Bass	9	103	54	109	44	6.7	0.7
Murray	9	24	54	37	28	5.8	0.4
Buckeye	8	160	34	156	72	6.9	0.7
Stuart	8	-13	73	26	19	4.8	0.1
Cusino	8	-2	60	55	27	5.2	0.3
Nevins	9	98	111	126	63	6.7	0.5
Monocle	10	209	49	202	125	7.0	0.6
Amdrus	8	15	21	66	35	5.5	0.8
Kelly	9	-5	43	49	22	5.1	0.2
Chris Brown	10	204	63	148	93	7.0	0.6
McGrath	8	3	56	46	32	5.3	0.5
Sunset	9	23	35	67	44	6.1	0.3
Vandercook	8	13	29	60	37	6.0	0.7
Greater Bass	8	6	36	61	41	5.4	0.5
Sand	11	-2	47	79	47	5.1	0.5
Nichols	10	24	28	62	52	5.8	0.6
Little Rock	14	10	45	43	43	5.9	1.2
Long	8	16	36	53	30	5.9	0.5
Clear	8	-6	20	40	29	4.9	0.4
Camp Twelve	9	-8	66	40	37	5.2	0.6
Lake Clara	9	39	30	84	44	6.4	0.9
Luna	9	7	42	61	43	5.7	0.9
Sugar Camp	8	-7	45	77	51	5.2	0.2

6.3 ALUMINUM CHEMISTRY

Inorganic (labile monomeric) Al has been identified as a potentially important toxicant in acidic waters in at least some regions (Driscoll et al. 1980, Wright et al. 1980, LaZerte 1984). Levels of inorganic Al were not measured during ELS-I. Thus, to supplement the ELS-I data base, measurements of Al chemistry were conducted in summer 1987 (Sections 3.5 and 4.1). The results indicate quite low levels (< 60 µg/L) of inorganic Al in all but one ELS-II lake in Subregion 2B (Lake 2B1-048, McNearney Lake, with 192 µg/L and pH 4.43) (Figure 6-3). Given that the values for pH measured in fall 1984 and summer 1987 were similar (Figure 6-2), levels of inorganic Al measured in summer 1987 are used directly with ELS-I chemistry values (for all other chemical variables) in assessing the association between fish communities and lake chemistry (see Section 8).

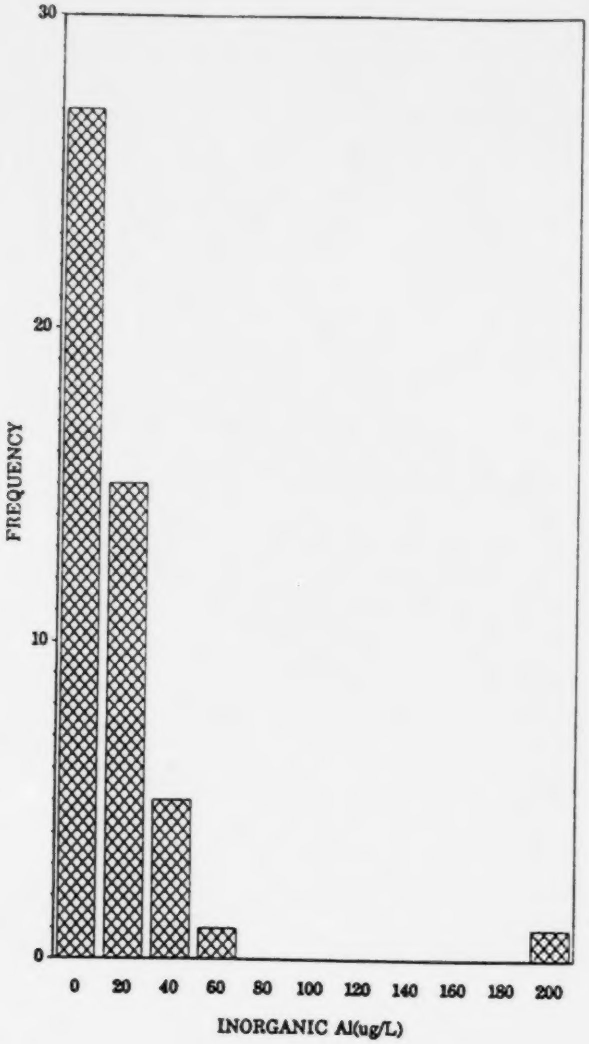

Figure 6-3. Distribution of inorganic aluminum in ELS-II lakes in Subregion 2B.

7. FISH COMMUNITY STATUS

Unless otherwise noted, the data and analyses presented in this section are based on a single sample per lake, collected between 8 June and 30 August 1987. Results from the duplicate surveys on 10 lakes, conducted between 31 August to 12 September 1987, are discussed and analyzed in Section 4.2. Measures of species richness and fish species presence/absence are discussed in Section 7.1; numbers of fish caught (indices of relative abundance) in Section 7.2; and information on fish size and condition factors in Section 7.3. The survey data for each lake are summarized in Appendix B.

7.1 FISH SPECIES DISTRIBUTION

Thirty-one fish species were caught in surveys of 49 lakes in Subregion 2B (Table 7.1).[1] Yellow perch was the most common species, collected in 31 lakes. Seven other species occurred in more than 10 lakes, in decreasing order of frequency: largemouth bass, bluegill sunfish (Lepomis macrochirus), pumpkinseed sunfish (Lepomis gibbosus), white sucker, brown bullhead (Ictalurus nebulosus), golden shiner (Notemigonus crysoleucas), and northern pike. The remaining 23 species were caught in less than 10 lakes, although some of these species were collected in large numbers in individual lakes (see Section 7.2). The types of fish caught in this survey are similar to those reported for lakes in other areas of the Upper Midwest (Wiener and Eilers 1987).

The number of fish species caught per lake varied between 0 and 13, with a median of 3 (Table 7.2). Two lakes (No Name, 2B1-038, and McNearney Lake, 2B1-048) had no fish caught. A third lake (Bohmier Lake, 2B2-078) had one fish species (brook stickleback, Culaea inconstans) caught during the initial survey but no fish caught during the duplicate QA/QC survey in September (Section 4.2). Six lakes (12.2%) had only yellow perch caught. Game fish, as defined in Section 3.6.2, were collected in 36 of the 49 lakes (73.5%).

In 11 lakes, beach seines could not be used because of the lack of suitable littoral area for seining (i.e., with relatively smooth substrate and free of obstructions and aquatic vegetation). In 16 of the 38 lakes in which beach seines were used (42%), beach

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[1] Includes a bluegill-pumpkinseed sunfish hybrid as a separate species. In no lakes were all three caught: bluegill sunfish, pumpkinseed sunfish, and the hybrid sunfish. Fish caught in lake 2B3-031 identified as brook trout were later determined to be splake (a hybrid cross between brook trout and lake trout) based on stocking records from the Michigan Department of Natural Resources, but are treated as brook trout in these analyses.

Table 7.1. Fish Species Caught and Frequency of Occurrence

		No. of Lakes in Which Species Caught		
Family and Species	Common Name	All Gear Types	Gill Net, Trap Net, & Angling	Gill Net & Trap Net
Salmonidae				
Salvelinus fontinalis	brook trout	4	4	4
Salvelinus namaycush	lake trout	1	1	1
Osmeridae				
Osmerus mordax	rainbow smelt	1	1	1
Umbridae				
Umbri limi	central mudminnow	6	5	5
Esocidae				
Esox lucius	northern pike	11	11	11
Cyprinidae				
Semotilus atromaculatus	creek chub	5	4	4
Notemigonus crysoleucas	golden shiner	12	12	12
Notropis cornutus	common shiner	7	7	7
Notropis atherinoides	emerald shiner	1	0	0
Notropis emiliae	pugnose minnow	1	0	0
Pimephales promelas	fathead minnow	3	2	2
Pimephales notatus	bluntnose minnow	7	2	2
Hybognathus hankinsoni	brassy minnow	1	0	0
Chrosomus neogaeus	finescale dace	6	5	5
Catostomidae				
Catostous commersoni	white sucker	14	14	14
Ictaluridae				
Ictalurus nebulosus	brown bullhead	13	13	13
Cyprinodontidae				
Fundulus diaphanus	banded killifish	1	0	0
Gasterosteidae				
Culaea inconstans	brook stickleback	3	3	3
Centrarchidae				
Ambloplites rupestris	rock bass	4	4	4
Micropterus dolomieui	smallmouth bass	5	4	4
Micropterus salmoides	largemouth bass	17	16	13
Lepomis gibbosus	pumpkinseed sunfish	15	15	15
Lepomis macrochirus	bluegill sunfish	16	13	13
Lepomis spp.	sunfish hydrid	3	3	3
Pomoxis nigromaculatus	black crappie	3	3	2
Percidae				
Perca flavescens	yellow perch	31	31	31
Stizostedion vitreum	walleye	2	2	2
Percina caprodes	logperch	1	0	0
Etheostoma nigrum	johnny darter	3	0	0
Etheostoma exile	Iowa darter	7	1	1
Cottidae				
Cottus bairdi	mottled sculpin	1	1	1

Table 7.2. Species Richness, by Lake, for the 49 Lakes Sampled in Subregion 2B

	Species Richness		
Lake ID	All Gear Types	Gill Net, Trap Net & Angling	Gill Net & Trap Net
2B1-016	-	2	1
2B1-022	-	4	4
2B1-035	1	1	1
2B1-038	0	0	0
2B1-039	-	2	2
2B1-040	-	2	2
2B1-041	6	5	5
2B1-042	1	1	1
2B1-047	2	2	2
2B1-048	0	0	0
2B1-052	1	1	1
2B1-061	3	3	3
2B1-064	1	1	1
2B1-066	1	1	1
2B2-004	-	3	3
2B2-007	4	3	3
2B2-024	7	6	6
2B2-038	8	5	5
2B2-044	3	3	3
2B2-049	-	1	1
2B2-055	1	1	1
2B2-061	6	5	5
2B2-074	3	3	3
2B2-075	-	4	4
2B2-078	1	1	1
2B2-079	1	1	1
2B2-082	4[a]	-	3
2B2-090	2	2	2
2B2-098	-	4[b]	3[b]
2B2-100	1[c]	1[c]	1[c]
2B3-007	4	3	3
2B3-008	-	4	4
2B3-009	12	10	10
2B3-012	8	6	6
3B3-013	3	3	3

(continued)

Table 7.2. Continued

Lake ID	Species Richness All Gear Types	Gill Net, Trap Net & Angling	Gill Net & Trap Net
2B3-020	-	7	7
2B3-023	9	9	9
2B3-027	4	2	2
2B3-028	7	6	5
2B3-030	4	4	4
2B3-031	13	9	9
2B3-034	9	7	7
2B3-037	11	9	9
2B3-051	1	1	1
2B3-055	11	8	8
2B3-056	2	2	2
2B3-057	-	7	6
2B3-058	1	1	1
2B3-071	9	8	8

[a] Lake not sampled by angling.
[b] Only one gill net fished.
[c] Only two (rather than three) trap nets fished.

seines collected additional species not caught with the other three gear types (Table 7.2). Small fish, particularly cyprinid (minnow) and darter species, were frequently collected only with beach seines (Table 7.1). Given that beach seines were not used in a relatively high percentage (22.4%) of lakes and that beach seines often collected fish species not caught with other gear types, species richness is calculated based on the catch from gill nets, trap nets, and angling, unless otherwise noted. Results from the beach seines are used only for comparisons among the 38 lakes in which beach seines were used. Species richness (based on fish caught with gill nets, trap nets, and angling) ranged between 0 and 9 species per lake, with a median of 3 (Table 7.2, Figure 7-1).

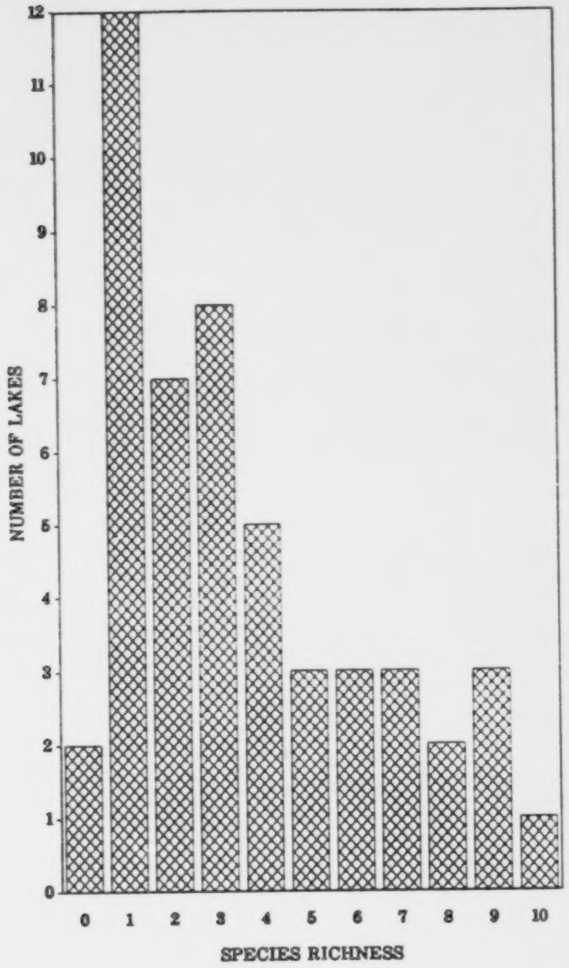


Figure 7-1. Distribution of species richness values among the 49 ELS-II lakes.

The effectiveness of each gear type in detecting fish presence varied somewhat among fish species (Tables 7.1 and 7.3). Salmonids (brook trout and lake trout) and largemouth and smallmouth bass were caught more frequently in gill nets than in trap nets, while the pumpkinseed sunfish, black crappie, and several minnow species were caught more often in trap nets than in gill nets. As noted above, beach seines were generally more effective at collecting cyprinids and darters than were other gear types. Angling was the least effective gear overall for detecting fish species presence, although the limited effort (total 2 man-hours) and time of day fished may have decreased angling efficiency. In a few lakes, largemouth bass (n=3 lakes) and black crappie (n=1 lake) were collected only with angling (Table 7.1).

Table 7.3. Relative Gear Efficiency for Each Species, Calculated as the Percent of Lakes for Which the Gear Detected Each Species Out of the Total Number of Lakes in Which the Species Was Caught Regardless of the Gear Used

Species	Relative Gear Efficiency (%)			
	Gill Net	Trap Net	Angling	Beach Seine[a]
Brook Trout	100	0	0	0
Lake Trout	100	0	0	0
Rainbow Smelt	100	0	0	0
Central Minnow	17	83	0	67
Northern Pike	82	55	36	0
Creek Chub	60	60	20	40
Golden Shiner	75	75	0	25
Common Shiner	57	43	0	29
Emerald Shiner	0	0	0	100
Pugnose Minnow	0	0	0	100
Fathead Minnow	0	67	0	33
Bluntnose Minnow	14	29	0	100
Brassy Minnow	0	0	0	100
Finescale Dace	17	67	0	67
White Sucker	93	79	0	0
Brown Bullhead	77	92	0	8
Banded Killifish	0	0	0	100
Brook Stickleback	0	100	0	100
Rock Bass	100	75	25	25
Smallmouth Bass	60	20	0	40
Largemouth Bass	71	24	29	24
Pumpkinseed Sunfish	33	100	0	27
Bluegill Sunfish	62	81	12	44
Sunfish Hybrid	33	67	0	0
Black Crappie	33	67	33	0
Yellow Perch	97	90	19	29
Walleye	50	50	0	0
Logperch	0	0	0	100
Johnny Darter	0	0	0	100
Iowa Darter	0	14	0	86
Mottled Sculpin	100	0	0	0

[a] Only 38 of the 49 lakes were sampled with beach seines.

7.2 TOTAL CATCH AND CATCH PER UNIT EFFORT

The numbers of fish caught per lake and the CPUE potentially may serve as indices of fish abundance, as discussed in Section 4.2. Catch rates from angling and beach seines tend to be highly variable. Thus, only fish caught in gill nets and traps nets are included in calculations of total catch and CPUE. Catch per unit effort is computed as the number of fish caught per hour per net, averaged over all the nets per lake for a given gear type (gill net or trap net).

Values for total catch and CPUE, summed across all fish species, are provided in Table 7.4 for each lake. Total catch ranged between 0 and 3000 fish, with a median of 210. Gill-net CPUE ranged between 0 and 16.2 fish/h/net, with a median of 0.83; trap-net CPUE from 0 to 67.2 fish/h/net, with a median of 1.33. For each of these variables, the distribution of values among the 49 lakes is highly skewed and non-normal (p=0.0001, Shapiro-Wilk test statistics, Conover 1980) (Figure 7-2).

Table 7.4. Total Catch and Catch Per Unit Effort (CPUE) by Lake, All Fish Species Combined

Lake ID	Total Catch	CPUE (fish/h/net)	
		Gill Net	Trap Net
2B1-016	6	0.03	0.06
2B1-022	28	0.13	0.27
2B1-035	407	2.45	3.40
2B1-038	0	0.00	0.00
2B1-039	378	3.53	1.76
2B1-040	138	1.35	0.74
2B1-041	218	1.12	1.52
2B1-042	1	0.00	0.01
2B1-047	748	3.03	9.67
2B1-048	0	0.00	0.00
2B1-052	1082	6.39	9.52
2B1-061	29	0.43	0.03
2B1-064	312	1.22	3.30
2B1-066	1	0.00	0.02
2B2-004	1058	0.60	21.17
2B2-007	210	0.82	2.30
2B2-024	344	0.23	5.24
2B2-038	364	1.33	5.02

(continued)

Table 7.4. Continued

Lake ID	Total Catch	CPUE (fish/h/net)	
		Gill Net	Trap Net
2B2-044	260	3.27	0.55
2B2-049	792	10.45	1.26
2B2-055	25	0.00	0.44
2B2-061	686	3.58	3.70
2B2-074	3000	0.50	67.23
2B2-075	129	0.83	1.12
2B2-078	1	0.00	0.01
2B2-079	386	5.21	1.82
2B2-082	33	0.36	0.14
2B2-090	1540	16.19	11.38
2B2-098	51	1.02	0.31
2B2-100	204	2.47	1.49
2B3-007	52	0.48	0.42
2B3-008	266	0.11	3.92
2B3-009	187	1.01	0.18
2B3-012	86	0.02	1.23
2B3-013	630	6.44	3.62
2B3-020	456	3.91	2.75
2B3-023	262	2.70	0.42
2B3-027	32	0.41	0.02
2B3-028	118	0.73	0.19
2B3-012	86	0.02	1.23
2B3-013	630	6.44	6.62
2B3-020	456	3.91	2.76
2B3-023	262	2.70	0.42
2B3-027	32	0.41	0.03
2B3-028	118	0.73	0.19
2B3-030	502	0.75	6.51
2B3-031	373	1.32	1.84
2B3-034	53	0.60	0.33
2B3-037	238	1.28	2.27
2B3-051	3	0.00	0.05
2B3-055	232	0.89	2.53
2B3-056	153	0.00	2.32
2B3-057	97	0.37	1.33
2B3-058	2403	4.91	27.52
2B3-071	163	1.46	0.67

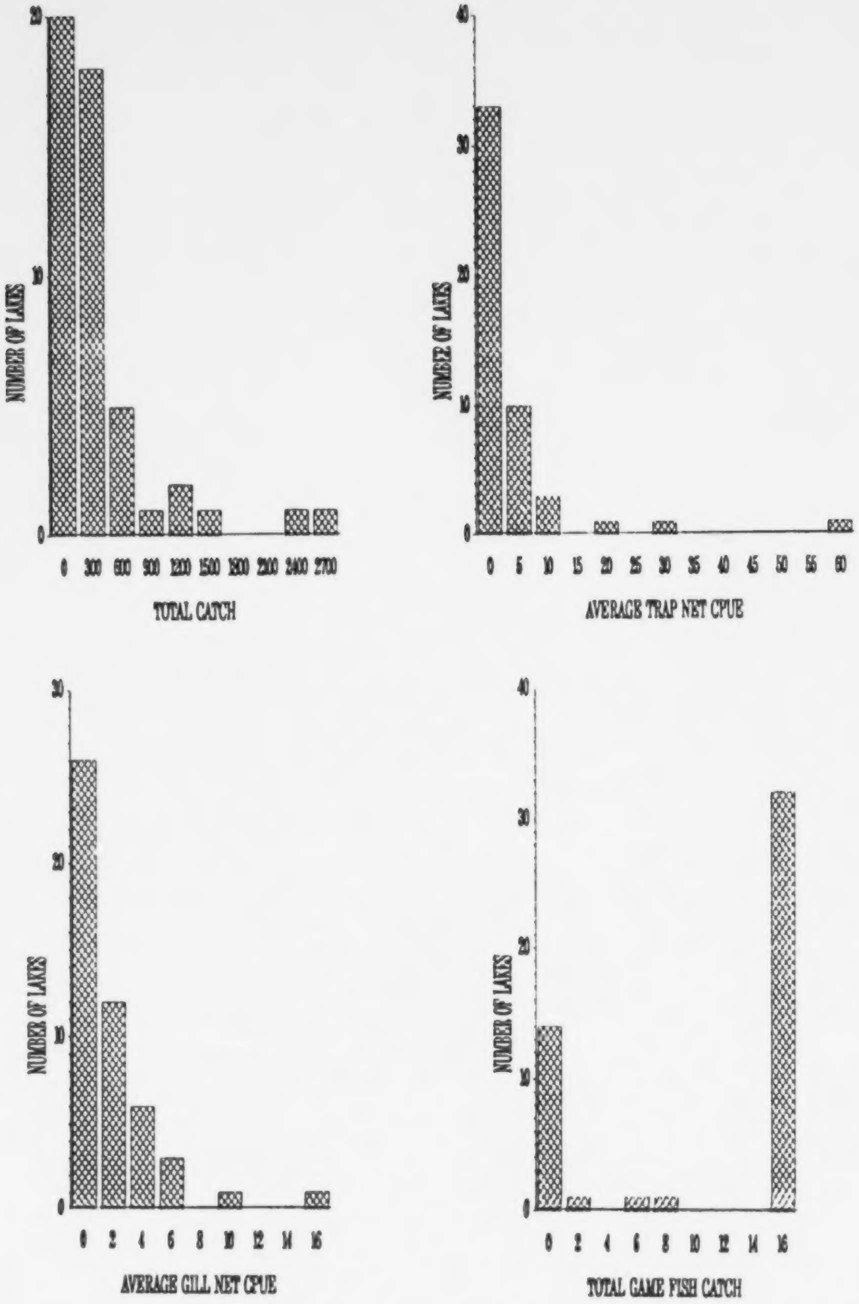


Figure 7-2. **Distribution of total catch, gill-net CPUE, and trap-net CPUE for all species, and total catch for game species for the 49 ELS-II lakes.**

Values for total catch and CPUE by fish species are summarized in Table 7.5, for those lakes in which each species was caught. Seven species had over 100 fish caught (in gill nets and trap nets) in at least one lake: golden shiner (maximum number caught per lake, 2318), brown bullhead (maximum 2403), yellow perch (maximum 1538), common shiner (maximum 1013), finescale dace (maximum 671), bluegill sunfish (maximum 458), and white sucker (maximum 229). In addition, creek chub and bluntnose minnow were caught in large numbers in beach seines in some lakes (maximum number caught per lake in all four gear types combined: creek chub 340; bluntnose minnow 279). For the 35 lakes with game fish caught in gill nets and trap nets, total catch ranged between 3 and 1538; gill-net and trap-net CPUE from 0.02 to 16.2 and 0.01 to 11.4 fish/h/net, respectively.

A Wilcoxon signed rank test was conducted to compare fish CPUE in gill nets versus trap nets (for all fish species combined, for game fish, and for each of the fish species caught in more than 10 lakes). No differences between gill nets and trap nets were detected ($p > 0.05$) for yellow perch, white sucker, golden shiner, and all species combined. Gill-net CPUE exceeded trap-net CPUE ($p \leq 0.05$) for largemouth bass, northern pike, and game fish as a group, while trap-net CPUE exceeded gill-net CPUE for brown bullhead, bluegill sunfish, and pumpkinseed sunfish.

7.3 FISH SIZE AND CONDITION FACTORS

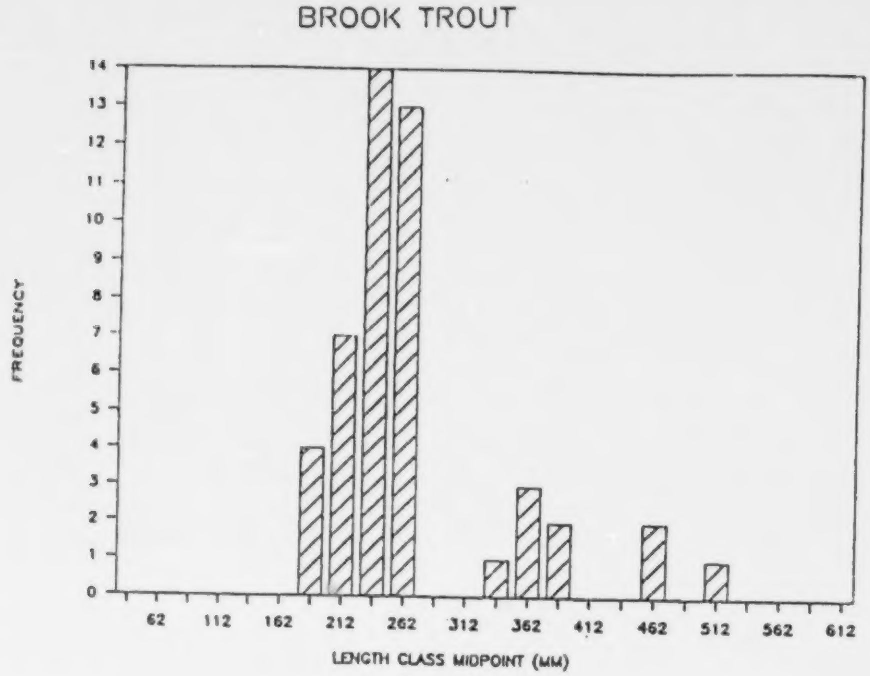
Length-frequency histograms, by species, combined across all lakes and all gear types (including duplicate samples where available), are presented in Figure 7-3 for the six target and index species with >10 fish caught (brook trout, northern pike, white sucker, smallmouth bass, largemouth bass, and yellow perch). Data for individual lakes, by species, are summarized in Appendix B. Fish age estimates and associated analyses of fish growth rates are discussed in the report on fish mercury bioaccumulation (EPA, in prep.).

Fish condition factors reflect the relationship between fish weight and fish length. The larger the condition factor, the heavier the fish for a given length, and presumably the healthier the fish. The condition factor, K, is often calculated as follows, assuming isometric growth (Anderson and Gutreuter 1983):

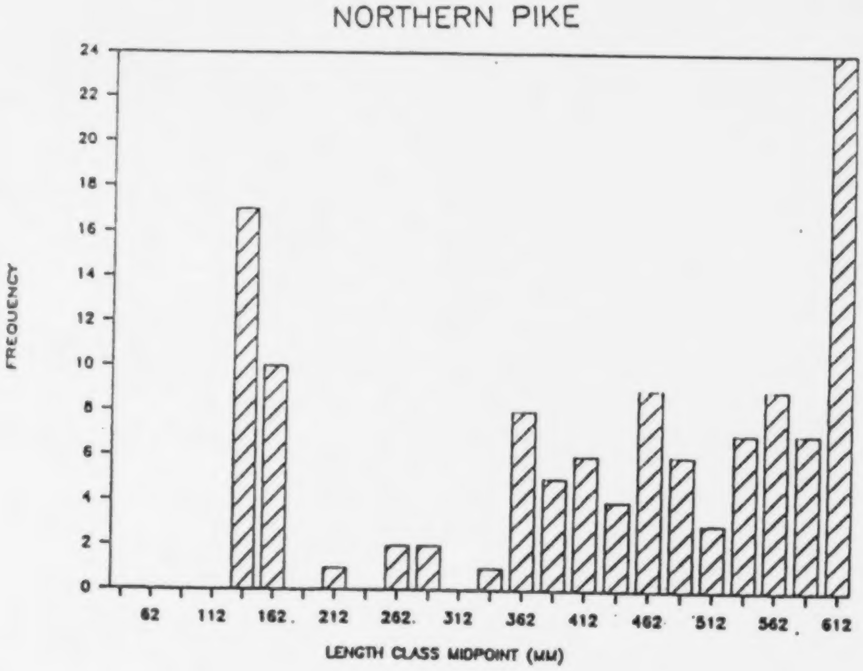
$$K = \frac{(weight * 10^5)}{(total\ length)^3}$$

Table 7.5. **Summary of Total Catch and Catch Per Unit Effort (CPUE) for Selected Species, for Lakes where the Fish Species Was Caught with Gill Nets or Trap Nets**

				CPUE (fish/h/net)			
		Total Catch		Gill Nets		Trap Nets	
Species/Group	No. Lakes	Median	Range	Median	Range	Median	Range
Game Fish	35	93	3-1538	0.98	0-16.17	0.30	0-11.37
Cyprinids	17	39	4-2989	0.08	0-1.48	0.42	0-66.99
Brook Trout	4	8	3-28	0.09	0.04-0.50	0	0-0
Lake Trout	1	2	2-2	0.01	0.01-0.01	0	0-0
Rainbow Smelt	1	41	41-41	0.25	0.25-0.25	0	0-0
Central Mudminnow	5	9	1-25	0	0-0.13	0.05	0.02-0.44
Northern Pike	11	7	1-43	0.06	0-0.52	0.01	0-0.03
Creek Chub	4	4.5	1-20	0.03	0-0.07	0.04	0-0.22
Golden Shiner	12	36	1-2318	0.14	0-1.41	0.34	0-51.73
Common Shiner	7	4	1-1013	0.02	0-0.26	0	0-20.92
Fathead Minnow	2	7	4-10	0	0-0	0.13	0.06-0.21
Bluntnose Minnow	2	12.5	10-15	0.01	0-0.02	0.20	0.18-0.22
Finescale Dace	5	14	1-671	0	0-0.03	0.25	0-15.26
White Sucker	14	30	2-229	0.20	0-1.54	0.06	0-2.68
Brown Bullhead	13	29	1-2403	0.06	0-4.91	0.27	0-27.52
Brook Stickleback	3	1	1-1	0	0-0	0.01	0.01-0.02
Rock Bass	4	21	11-25	0.08	0.04-0.14	0.09	0-0.27
Smallmouth Bass	4	1.5	1-17	0.01	0-0.02	0	0-0.10
Largemouth Bass	13	3	1-29	0.04	0-0.42	0	0-0.06
Pumpkinseed	15	8	1-63	0	0-0.59	0.08	0.01-0.73
Bluegill	13	52	2-458	0.08	0-0.70	0.27	0.02-6.45
Sunfish Hybrid	3	2	2-38	0	0-0.03	0.04	0-0.60
Black Crappie	2	6	1-11	0.09	0-0.18	0.02	0.01-0.02
Yellow Perch	31	116	2-1538	0.98	0-16.17	0.47	0-11.37
Walleye	2	4.5	1-8	0.05	0-0.10	0.01	0.01-0.01
Iowa Darter	1	1	1-1	0	0-0	0.01	0.01-0.01
Mottled Sculpin	1	1	1-1	0.01	0.01-0.01	0	0-0



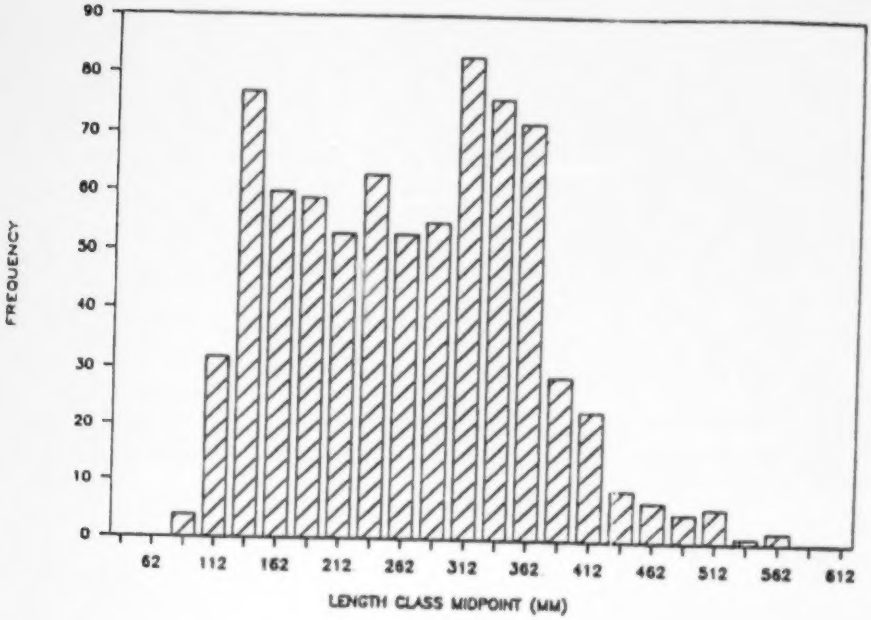
BROOK TROUT



NORTHERN PIKE

Figure 7-3. **Length-frequency histograms, by species, for all fish caught in all gear types in all lakes.**

WHITE SUCKER



SMALLMOUTH BASS

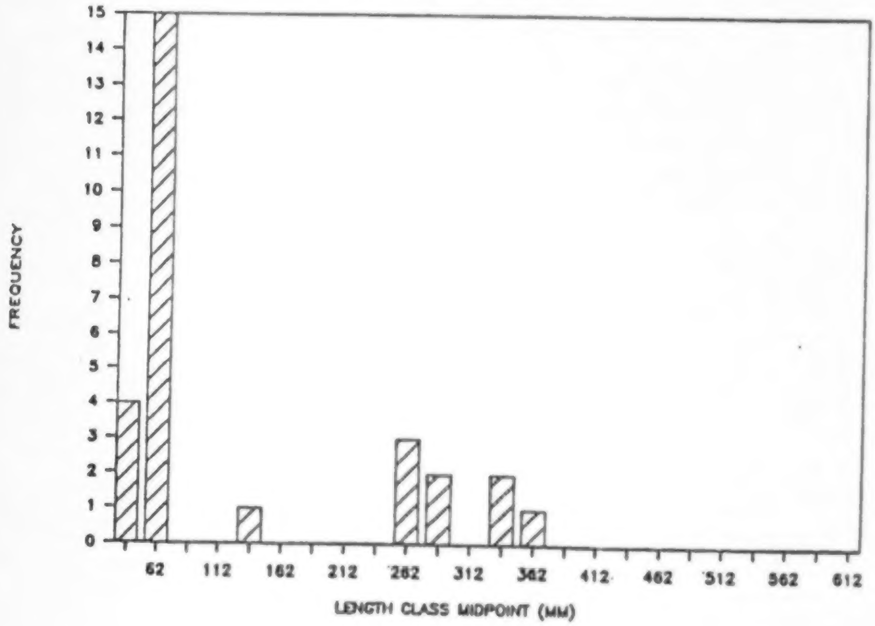


Figure 7-3. Continued

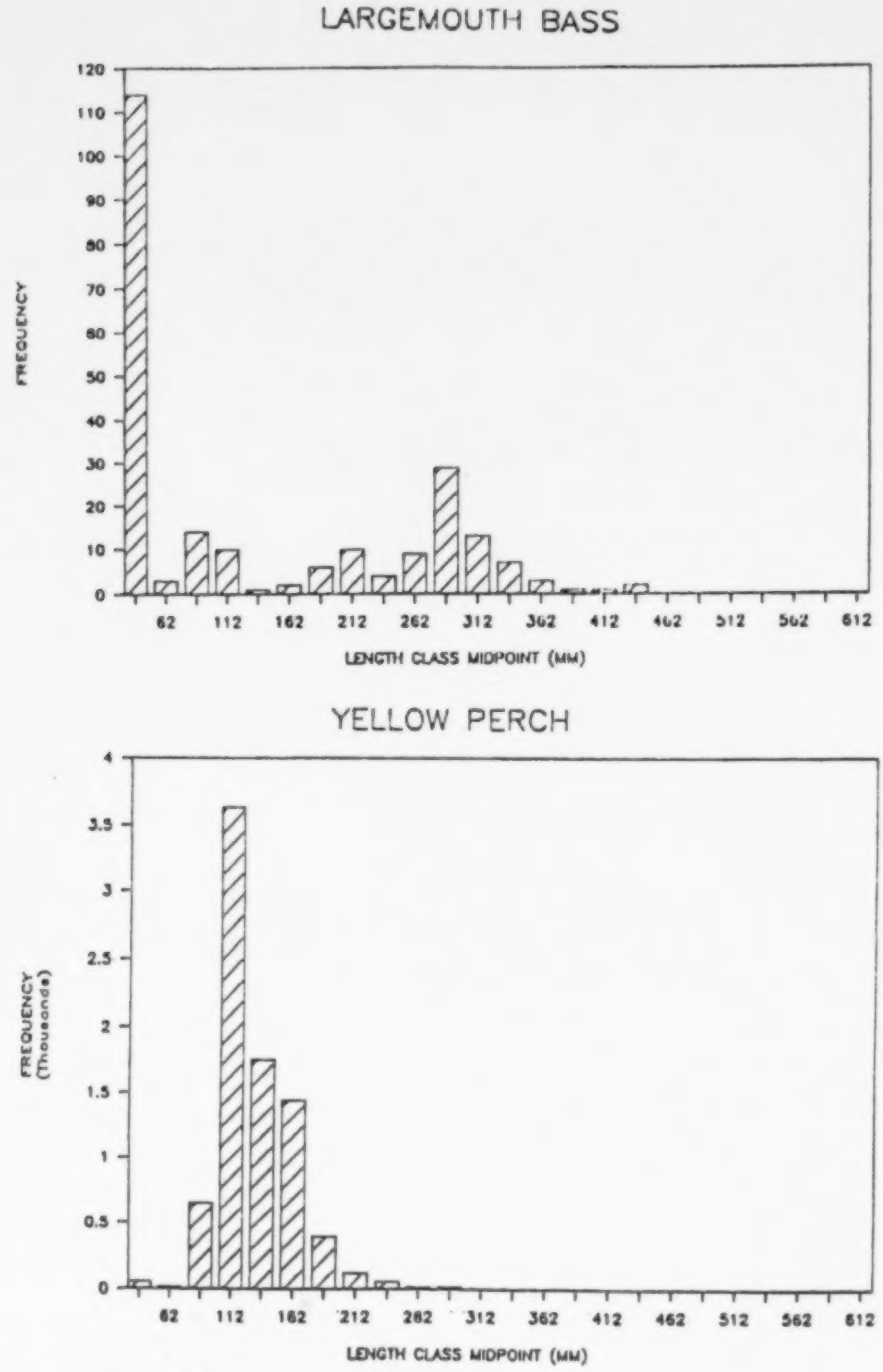
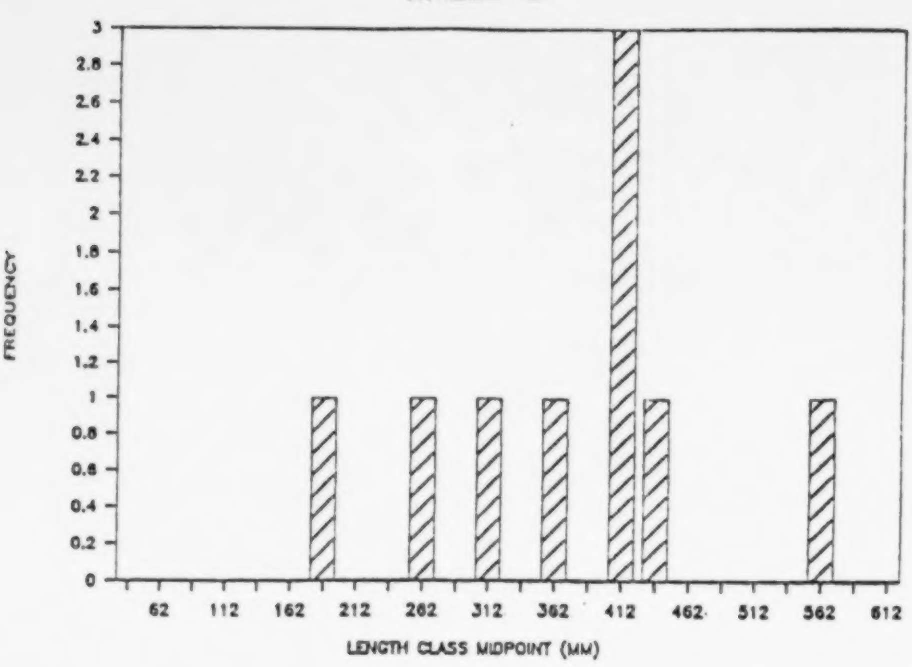


Figure 7-3. Continued



Condition factors for the 10 species measured for length and weight pooled across all lakes and all fish caught (including duplicate samples) are summarized in Table 7.6. Values tend to be species-specific, reflecting differences in fish shape. Fish condition factors also vary with season of the year, sex, stage of maturity, and size of the fish (Everhart et al. 1975). For the three species for which statewide average condition factors could be calculated (northern pike, largemouth bass, and yellow perch), values for the ELS-II tended to be similar to or slightly lower than the statewide averages.

Table 7.6. **Fish Condition Factors, by Species, Pooled Across All Lakes and All Ages**

		Condition Factor			
Species	**N**	**Range**	**Std. Dev.**	**Mean**	**Statewide Average**[a]
Brook Trout	27	0.78-1.70	0.24	1.13	-
Northern Pike	91	0.31-0.75	0.08	0.55	0.54-0.65
White Sucker	288	0.38-1.50	0.15	1.00	-
Rock Bass	14	1.42-2.23	0.19	1.87	-
Smallmouth Bass	6	1.15-1.55	0.16	1.32	-
Largemouth Bass	106	0.89-2.51	0.22	1.32	1.19-1.50
Pumpkinseed Sunfish	27	1.52-2.42	0.23	2.01	-
Bluegill Sunfish	46	0.97-2.00	0.20	1.51	-
Yellow Perch	1178	0.22-1.77	0.16	1.00	1.06-1.25
Walleye	8	0.79-0.99	0.06	0.85	-

[a] Statewide average values calculated by age class based on data presented in Merna et al. (1981); ranges for ages 0 to 9 for northern pike, 0 to 10 for largemouth bass, and 1 to 11 for yellow perch. Generally, younger, smaller fish have lower condition factors.

8. ASSOCIATION BETWEEN FISH COMMUNITY STATUS AND LAKE CHARACTERISTICS

The ELS-II data for Subregion 2B may be used to develop and examine hypotheses regarding the role of selected environmental factors in determining fish population success and fish community characteristics in lakes in the Upper Peninsula of Michigan and northeastern Wisconsin. Survey data alone, however, cannot establish causality. Caution must be exercised not to assume that observed spatial associations imply a direct cause-and-effect relationship. Many factors influence fish community status, and most of these factors are themselves interrelated and correlated.

A wide range of alternative predictor variables were examined that may directly or indirectly influence fish community characteristics:

- Lake type -- It is expected that seepage lakes, without inlets and outlets, would have reduced rates of colonization and thus naturally lower numbers of species and perhaps lower fish abundance. Drainage lakes, reservoirs, and closed lakes, on the other hand, have connecting lakes and streams that may serve both as potential refuges during severe conditions and as source areas for potential immigrants (Tonn and Magnuson 1982). For analyses of fish community status, lake type is defined as a binary variable, seepage versus nonseepage lakes.

- Lake area — Many investigators have reported a positive association between lake area and species richness (Magnuson 1976, Harvey 1979, Rago and Wiener 1986). Larger lakes generally provide greater habitat complexity and also are more likely to include refuge areas during adverse environmental conditions.

- Lake depth (based on the ELS-I site depth) — Shallower lakes are less likely to be thermally stratified, and thus are less likely to support fish species intolerant of relatively warm water temperatures. It should be noted that the ELS-I site depth is only a rough approximation of lake maximum depth (Linthurst et al. 1986). Unpublished data for lakes in the northeastern United States indicate relatively poor agreement between the ELS-I site depth and the true maximum depth in some lakes.

- Elevation — Lakes at higher elevations tend to be cooler, favoring fish species less tolerant of higher water temperatures. In addition, lakes at higher elevations may experience longer periods of ice cover and as a result may be more susceptible to oxygen depletion during the winter.

- Dissolved oxygen — Fish require adequate levels of DO to survive, although minimum tolerance levels vary among fish species. Variations in DO concentrations over the three-month sampling period may limit, however, the utility of the ELS-II measurements for among-lake comparisons. Two indices are computed from the ELS-II measurements: the minimum measured level of DO and the proportion of the water column with DO levels below 4 mg/L.

- Thermal stratification — The optimum temperature for fish survival and growth varies among fish species. Thus, water temperatures play a major role in determining fish community composition in surface waters. ELS-II water temperature measurements were collected over a three-month period and are not considered suitable for direct among-lake comparisons. Analyses of fish community status, therefore, include only a binary index of thermal stratification, as defined in Section 5.

- Secchi depth — Secchi depth is a measure of light transparency and penetration, which in turn affects the lake thermal regime and light availability for primary production. In addition, some fish species (e.g., fish that rely heavily on visual prey selection) are relatively intolerant of turbid waters.

- Lake pH — Low levels of pH may be toxic to fish (Altshuller and Linthurst 1984). Low pH levels may result from naturally acidic conditions, from acidic deposition, or from other sources of acidity. Specific causes for low pH waters in Subregion 2B are not examined in this document (see Eilers et al. 1988).

- Inorganic aluminum — High levels of inorganic Al may be toxic to fish. Aluminum and pH (or the hydrogen ion concentration) are the principal toxic agents for fish in acidic waters (Schofield and Trojnar 1980, Driscoll et al. 1980).

- Calcium — Higher levels of Ca may mitigate the potential toxic effects of low pH and elevated levels of inorganic Al. Fish tolerate lower pH levels and higher Al concentrations in waters with higher Ca concentrations (Brown 1983, Ingersoll 1986).

- Dissolved organic carbon — High levels of DOC may complex Al and other metals thereby decreasing metal toxicity (Driscoll et al. 1980, Parkhurst 1987). High levels of DOC (and water color, discussed below) are in some cases indicative of lakes with high levels of organic acids and/or extensive bog development. Lakes with high levels of DOC tend to have higher water temperatures (due to the effect of dissolved organics on light adsorption in water). Lakes with extensive bog development may be subject to periodic oxygen depletion. The occurrence of bog development was not directly assessed in either the ELS-I or ELS-II.

- Color — Levels of DOC and water color are generally highly correlated. However, neither is an exact measure of the availability of organics for metal complexation or of organic acidity. Thus, both variables are included as potential predictor variables of fish community status.

- Acid neutralizing capacity — Acidification is defined as the loss of ANC. Acidic waters are defined by ANC ≤ 0 µeq/L. While ANC, by itself, may have no direct effects on fish survival, variations in the relationship between ANC and pH may reflect the varying importance of weak acids (including Al and organic acids), which in turn may influence fish survival and fish community composition.

- Sum of the base cations — Studies have demonstrated that Na, Mg, and K may also influence the toxicity of acidic waters to fish, although to a lesser degree than does Ca (Altshuller and Linthurst 1984).

- Extractable Al — Procedures for the fractionation and speciation of Al are still fairly controversial. Thus, in addition to inclusion of the estimated inorganic Al, noted above, measured values for extractable Al (i.e., total monomeric Al) from ELS-I are also considered.

- Total phosphorus (P) — Phosphorous is the key nutrient controlling primary productivity in most temperate, inland lakes (Schindler 1975). Levels of total P are often positively correlated with levels of algal standing crop (Nicholls and Dillon 1978, Schindler 1975), and may in turn influence fish abundance.

- Sulfate — Levels of SO_4 measured during ELS-I are included as a potential index of the influence of SO_4 deposition on lake chemistry. However, in-lake SO_4 reduction, especially in seepage lakes, may alter markedly regional patterns in lake SO_4. Sulfate in lakes in Subregion 2B likely has no direct measurable effects on fish.

- Silica -- Seepage lakes tend to have lower levels of SiO_2 than do drainage lakes, reservoirs, or closed systems (Linthurst et al. 1986). In addition, varying levels of SiO_2 among seepage lakes may be indicative of the varying importance of groundwater inflow to lake-ion budgets. Silica has no direct effects on fish, but may serve as an independent index of lake type and of the importance of watershed processes to lake chemistry.

The analyses in this document are considered exploratory. In order not to limit data analyses to factors considered most important a priori, a large number of statistical tests have been conducted involving all of the above parameters. Of primary interest is the pattern of results and the consistency of these results with proposed mechanisms of effects, rather than any one test per se. While some adjustment is made for the number of tests conducted, individual spurious results may still occur.

Relationships between fish community characteristics and lake physical and chemical attributes were evaluated using nonparametric statistics and regression analyses. As part of each regression analysis, appropriate model diagnostics were examined, including residual plots, normal plots, Cook's D influence statistic, and the condition index (Belsley et al. 1980, Myers 1986). These tools were used to assess model adequacy, to inspect for homogeneity of variance and collinearity problems, to detect outliers and influential data points, and to test for normality.

The sample of 49 ELS-II lakes was assumed to be a sample from an infinite population. Therefore, all analyses in this section are unweighted and do not include the ELS-II weighting factors defined during lake selection (Section 2.2.2). The objective is to better understand processes and factors that influence fish community status and fish distribution. Use of the ELS-II weighting factors to extrapolate from the sample of 49 lakes to the ELS-II target population is presented in Section 9.

Consistent with the basic format used in other sections, among-lake patterns in fish community characteristics are discussed for each measured response variable in the following order: species richness (Section 8.2), fish species presence/absence (Section 8.3), total catch and CPUE (Section 8.4), and fish size and condition factors (Section 8.5). Section 8.1 contains an evaluation of multicollinearity among the 19 predictor variables of interest (i.e., the lake physical and chemical attributes described above). As in Section 7, unless otherwise noted, the data and analyses presented are based on a single sample per lake, collected between 8 June and 30 August 1987. Results from duplicate surveys on 10 lakes, conducted 31 August to 12 September, are discussed and analyzed in Section 4.2.

8.1 MULTICOLLINEARITY AMONG PREDICTOR VARIABLES

Many of the predictor variables considered are themselves highly correlated (Table 8.1), causing problems with both model interpretation and inflated variance terms for regression parameter estimates. Among-lake variations in lake pH, for example, were significantly correlated ($\alpha=0.05$, adjusted for 16 tests per variable, $p \leq 0.0031$) with ANC ($r=0.99$, Spearman's rank correlation), the sum of base cations ($r=0.81$), Ca ($r=0.77$), extractable Al ($r=-0.68$), SiO_2 ($r=0.63$), and DOC ($r=0.45$), and to a lesser degree ($0.0031 < p \leq 0.05$) with inorganic Al ($r=-0.41$) and lake area ($r=0.39$). Seepage lakes had significantly lower levels of ANC, Ca, sum of base cations, color, and SiO_2 than did nonseepage lakes (Section 6.1, Table 6.2). These strong associations among key predictor variables of interest make it difficult to determine the relative importance of individual lake characteristics as factors influencing observed among-lake variations in fish communities.

To quantify these patterns and associations among predictor variables, a principal component analysis (Pielou 1984) was conducted on the full set of 19 chemical and physical variables. Both nontransformed and log-transformed data were evaluated and yielded similar results. The final data set consisted of a combination of nontransformed and log-transformed variables, selected after examining the relationship between individual predictor variables and the fish response data (see Sections 8.2 and 8.3). A constant (100 µeq/L) was added to ANC prior to the logarithmic (base e) transformation, to adjust for ANC values ≤ 0. Concentrations of extractable Al, inorganic Al, SiO_2, and total P ≤ 0 were converted to the lowest recorded positive value for the variable in

Table 8.1. Correlation Matrix for the 17 Continuous Predictor Variables[a]

	Area	Depth	Elev.	Min. DO	% DO < 4 mg/L	Secchi Depth	pH	ANC	Inorg. Al	Ext. Al	Ca	Sum Base Cations	DOC	Color	SO_4	SiO_2	Total P
Area	1.0	ns	ns	.31	ns	ns	.39	.35	ns	ns	.51*	.51*	ns	ns	.40	ns	ns
Depth		1.0	ns	-.61*	.65*	.47*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Elevation			1.0	ns	ns	ns	ns	ns	ns	.28	ns	ns	ns	.32	ns	ns	ns
Min. DO				1.0	-.84*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
% DO < 4					1.0	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Secchi Depth						1.0	ns	ns	ns	ns	ns	ns	-.61*	-.77*	ns	-.42*	-.39
pH							1.0	.99*	-.41	-.68*	.77*	.81*	.45*	ns	ns	.63*	ns
ANC								1.0	-.40	-.66*	.80*	.83*	.50*	.29	ns	.69*	ns
Inorg. Al									1.0	.59*	ns	ns	ns	ns	.45*	ns	ns
Ext. Al										1.0	-.38	-.37	ns	ns	ns	-.30	ns
Ca											1.0	.98*	.40	.30	.43*	.71*	ns
Base Cations												1.0	.43*	.34	.40	.70*	ns
DOC													1.0	.75*	ns	.55*	.34
Color														1.0	ns	.55*	.39
SO_4															1.0	ns	ns
SiO_2																1.0	ns
Total P																	1.0

[a] Analyses based on Spearman's rank correlation. Numbers in matrix indicate correlation coefficients for comparisons with $p \leq 0.05$. Asterisks indicate significance at $\alpha = 0.05$, adjusted for 16 tests per variable ($p < 0.0031$). Comparisons nonsignificant with $p > 0.05$ are identified as ns.

the ELS-II data set (1 µg/L, 0.1 µg/L, 0.02 mg/L, and 0.5 µg/L, respectively) for log-transformation. In each instance, these lowest recorded values were below the minimum system detection limit defined in Linthurst et al. (1986).

Separate principal component analyses were conducted for the full set of 49 ELS-II lakes in Subregion 2B and for the 38 lakes sampled with beach seines. Coefficients for the first five principal components accounted for 82.8% and 85.2% of the total variation in the 49-lake and 38-lake data sets, respectively; the first two principal components accounted for 49.5% and 53.9% of the variation in the two data sets (Table 8.2). In both data sets, the first principal component was defined primarily by terms related to watershed weathering: Ca, the sum of base cations, lake pH, ANC, and SiO_2. The second principal component was determined largely by levels of DO, lake depth, and the occurrence of thermal stratification. The relationships between these principal components and fish response variables (species richness and fish species presence/absence) are assessed in Sections 8.2 and 8.3.

8.2 SPECIES RICHNESS

Initially, simple associations between species richness and each lake characteristic of interest were examined using nonparametric statistical tests: Spearman's rank correlations for continuous predictor variables (e.g., lake pH) and the Wilcoxon rank sum and Kolmogorov-Smirnov tests for binary predictor variables (i.e., lake type and the occurrence of thermal stratification). The results were similar for the 49-lake data set (with species richness defined by catch from gill nets, trap nets, and angling) and the 38-lake data set (using the number of species caught in all four gear types, see Section 7.1). Species richness was significantly correlated ($\alpha=0.05$, adjusted for 19 tests per data set, $p \leq 0.0026$) with eight lake attributes: lake type, pH ($r=0.74$ for the 49-lake data set), ANC ($r=0.74$), sum of base cations ($r=0.65$), Ca ($r=0.64$), SiO_2 ($r=0.60$), extractable Al ($r=-0.45$), and DOC ($r=0.42$) (Table 8.3; Figures 8-1 and 8-2). Additional correlations with $0.0026 < p \leq 0.05$ include lake area, minimum DO, the occurrence of thermal stratification, depth, and SO_4.

Multivariate models of species richness as a function of lake physical and chemical characteristics were developed and explored using ordinary least-squares (OLS) regression analysis (Myers 1986). As a first-step in OLS regression, single-variable models and bivariate plots were examined for each variable to evaluate the need for data transformations and to detect outliers and influential data points. For lake area, depth, elevation, Ca, sum base cations, ANC, color, extractable Al, and total P, the log-

Table 8.2. Results from Principal Components Analysis on 19 Physical and Chemical Variables

	Principal Component 1		Principal Component 2		Principal Component 3	
Variable	**49 Lakes**	**38 Lakes**	**49 Lakes**	**38 Lakes**	**49 Lakes**	**38 Lakes**
pH	0.369	0.363	-0.043	-0.011	0.066	0.048
ln (Ca)	0.379	0.370	-0.055	-0.028	0.135	0.151
DOC	0.211	0.216	-0.106	-0.195	-0.360	-0.299
ln (Inorg.Al)	-0.029	-0.022	0.047	0.032	0.035	0.104
ln (Sum Base Cations)	0.385	0.374	-0.060	-0.038	0.121	0.140
ln (ANC)	0.383	0.375	-0.037	-0.013	0.110	0.098
ln (Color)	0.150	0.142	-0.125	-0.240	-0.465	-0.417
ln (Ext Al)	-0.207	-0.217	-0.003	-0.069	-0.173	-0.055
SO_4	0.156	0.155	0.073	0.090	0.271	0.328
SiO_2	0.366	0.362	-0.029	-0.029	0.033	0.040
ln (Total P)	0.075	0.113	-0.103	-0.162	-0.250	-0.220
ln (Area)	0.208	0.218	-0.132	-0.048	0.198	0.261
ln (Depth)	0.092	0.110	-0.478	0.454	0.097	-0.016
ln (Elevation)	0.014	-0.019	-0.085	-0.061	-0.221	-0.214
ln (Secchi Depth)	-0.107	-0.095	0.208	0.358	0.457	0.362
Lake Type[a]	-0.263	-0.283	-0.088	-0.014	0.169	0.175
Minimum DO	-0.076	-0.062	0.478	-0.432	0.184	0.295
% O_2 < 4 mg/L	0.090	0.077	0.425	0.367	-0.237	-0.325
Thermal Strat.[a]	0.066	0.099	0.480	0.446	-0.109	-0.206
Eigenvalue	6.091	6.432	3.309	3.811	2.968	2.409
Proportion of Total Variance	0.321	0.339	0.174	0.201	0.156	0.127
Cumulative Variance Explained	0.321	0.339	0.495	0.539	0.651	0.666

(continued)

Table 8.2. Continued

Variance	Principal Component 4		Principal Component 5	
	49 Lakes	38 Lakes	49 Lakes	38 Lakes
pH	-0.172	-0.130	0.135	-0.172
ln (Ca)	0.004	-0.018	-0.001	-0.057
DOC	0.061	0.182	0.104	-0.016
ln (Inorg. Al)	0.566	0.512	-0.253	0.306
ln (Sum Base Cations)	0.002	-0.018	0.010	-0.074
ln (ANC)	-0.109	-0.115	0.001	-0.090
ln (Color)	0.140	0.205	0.025	0.022
ln (Ext. Al)	0.489	0.484	-0.060	0.130
SO_4	0.446	0.387	0.000	0.058
SiO_2	0.075	0.035	-0.077	0.040
ln (Total P)	0.148	-0.207	-0.608	0.603
ln (Area)	0.276	0.282	0.079	0.073
ln (Depth)	0.022	0.045	-0.023	0.052
ln (Elevation)	0.178	0.312	0.677	-0.653
ln (Secchi Depth)	0.038	0.019	0.037	0.029
Lake Type[a]	-0.183	-0.131	0.214	-0.192
Minimum DO	0.054	-0.001	-0.090	0.001
% O_2 < 4mg/L	0.017	0.082	0.067	0.001
Thermal Strat.[a]	-0.046	0.006	-0.030	0.033
Eigenvalue	2.139	2.365	1.226	1.163
Proportion of Total Variance	0.113	0.124	0.065	0.061
Cumulative Variance Explained	0.764	0.790	0.828	0.852

[a] Lake type and thermal stratification are coded as binary variables. Lake type = 1 for seepage lakes and 0 for nonseepage lakes. Thermal stratification = 1 for lakes thermally stratified at the time of sampling and 0 for nonstratified lakes.

transformation (base e) resulted in a higher model coefficient of determination, an improved residual plot (improved homogeneity of variance), and/or fewer outliers with less influence on the regression (based on Cook's D statistic) relative to the nontransformed data. For minimum DO, percent of the water column with DO < 4 mg/L, DOC, and SiO_2, the nontransformed data resulted in a better OLS model

Table 8.3. Association Between Species Richness, Total Catch, and Catch Per Unit Effort (CPUE, Averaged Over Gill Nets and Trap Nets) and Lake Physical and Chemical Characteristics

	Species Richness			
Variables	**49 Lakes**	**38 Lakes**	**Total Catch**	**CPUE**
Lake Type	*	*	ns	ns
Area	0.39	0.38	ns	ns
Depth	ns	0.38	ns	-0.30
Elevation	ns	ns	ns	ns
Min. DO	-0.31	-0.36	ns	ns
% DO < 4 mg/L	ns	ns	ns	ns
Therm. Strat.	x	x	ns	ns
Secchi Depth	ns	ns	-0.38	-0.40
pH	0.74*	0.79*	ns	ns
Inorg. Al	ns	ns	ns	-0.29
Ca	0.64*	0.68*	ns	ns
DOC	0.42*	0.45	ns	ns
Sum Base Cations	0.65*	0.68*	ns	ns
ANC	0.74*	0.79*	ns	ns
Color	ns	ns	ns	ns
Ext. Al	-0.45*	-0.48*	ns	ns
SO_4	0.31	ns	ns	ns
SiO_2	0.60*	0.68*	ns	ns
Total P	ns	ns	ns	ns

[a] Analyses based on Spearman's rank correlation for continuous variables and Wilcoxon rank sum and Kolmogorov-Smirnov tests for binary variables (lake type and thermal stratification). Tests with $p > 0.05$ noted as ns (not significant). Numbers indicate correlation coefficients for comparisons with $p \leq 0.05$. Asterisks indicate tests significant at $\alpha = 0.05$, adjusted for 19 tests per variable ($p \leq 0.0026$). Results for binary variables with $0.0026 < p \leq 0.05$ noted by an x.

with species richness. Analyses for Secchi depth, inorganic Al, and SO_4, were inconclusive; therefore, for consistency with other similar variables in the data set and with the logistic models of fish presence/absence (Section 8.3), log-transformed data were used for Secchi depth and inorganic Al and nontransformed data for SO_4.

Transformation of the dependent variable, species richness, was also considered. A Box-Cox analysis (Box and Cox 1964) for linear models of species richness fit to pH

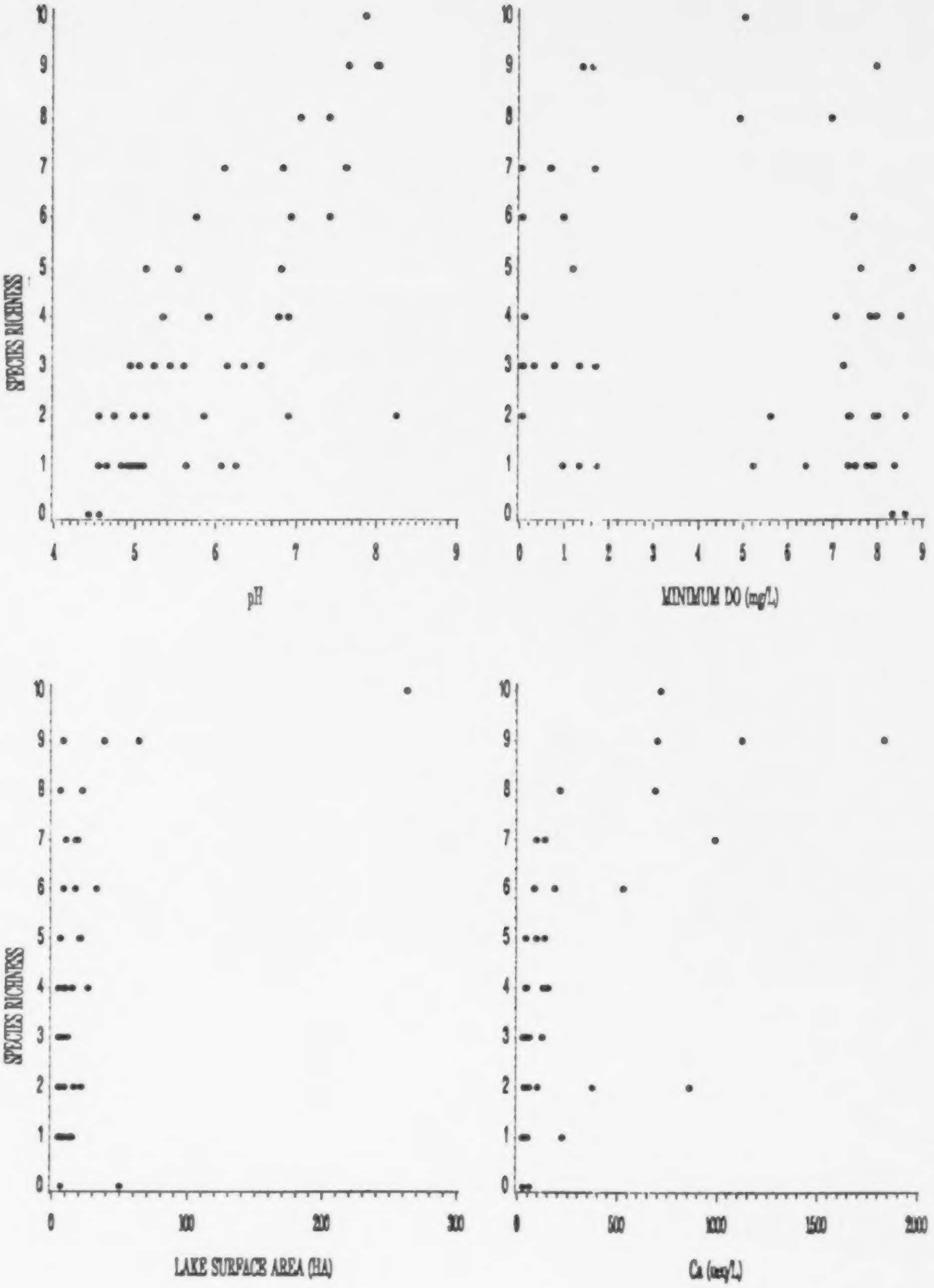


Figure 8-1. Bivariate plots of species richness and lake characteristics, for those continuous physical and chemical variables associated with species richness at $p \leq 0.05$ (see Table 8.3).

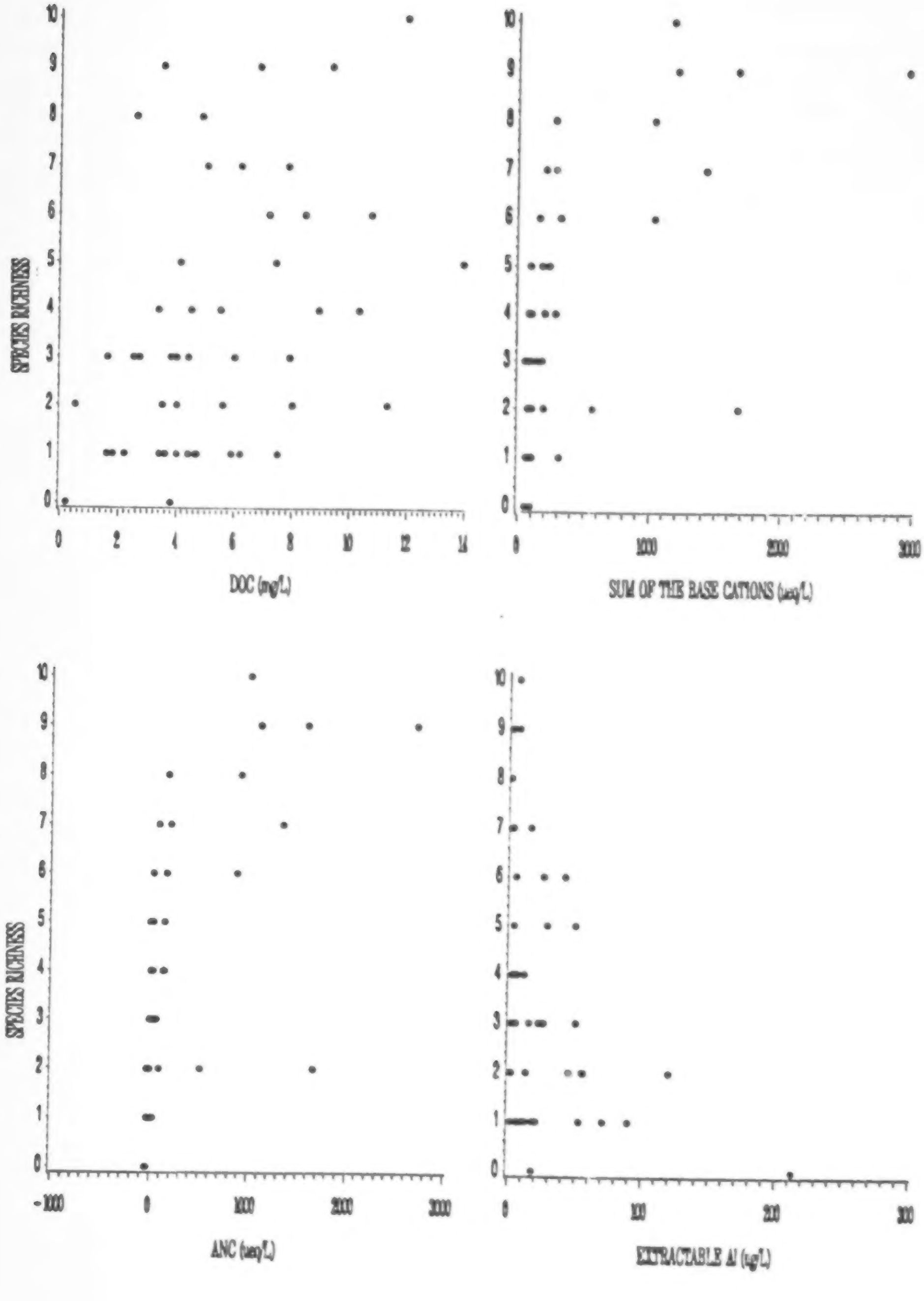


Figure 8-1. Continued.

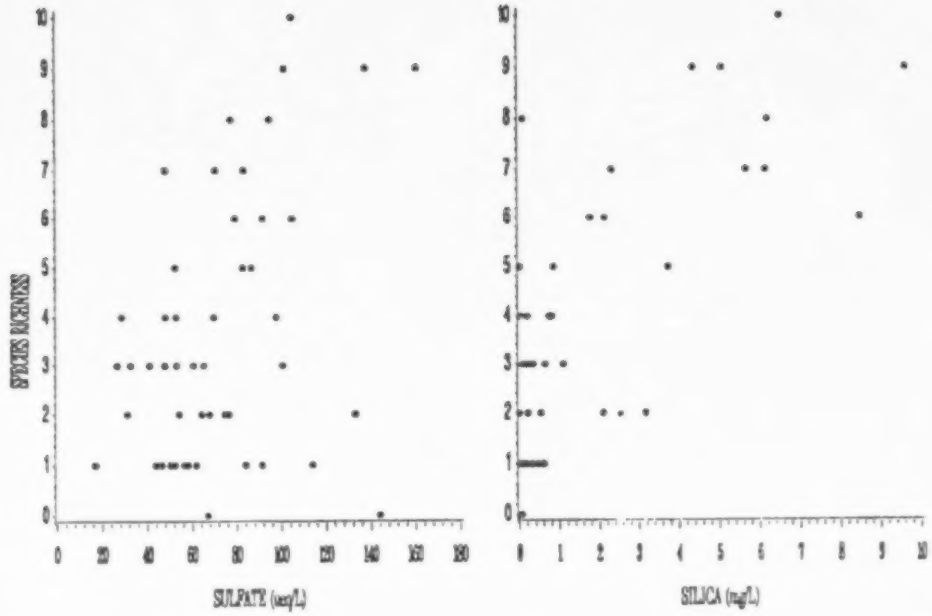


Figure 8-1. Continued.

and Ca indicated no need for transformation. Thus, in the analyses that follow, species richness was used directly without transformation.

For several predictor variables of interest, examination of the residual plots for the single-variable OLS models indicated one or two outliers and/or influential data points. Typically, these outliers/influential data points represented lakes with values at the high end of the range for the 49 ELS-II lakes. The specific lake identified varied, however, among predictor variables. In addition, there was no indication that errors in data collection or recording could account for these outliers. Thus, no data points were discarded from subsequent analyses, although the effects of outliers on model results were continually examined as part of model development.

Three approaches - stepwise forward and backward and maximum r^2 OLS regressions - were conducted to examine the relationship between species richness and multiple lake attributes. For the 49-lake data set, all three approaches identified the same model, predicting species richness as a function of three variables (Table 8.4): lake pH, SiO_2, and the occurrence of thermal stratification (model r^2=0.69). On the other hand, for the 38-lake data set (including species collected with beach seines), each

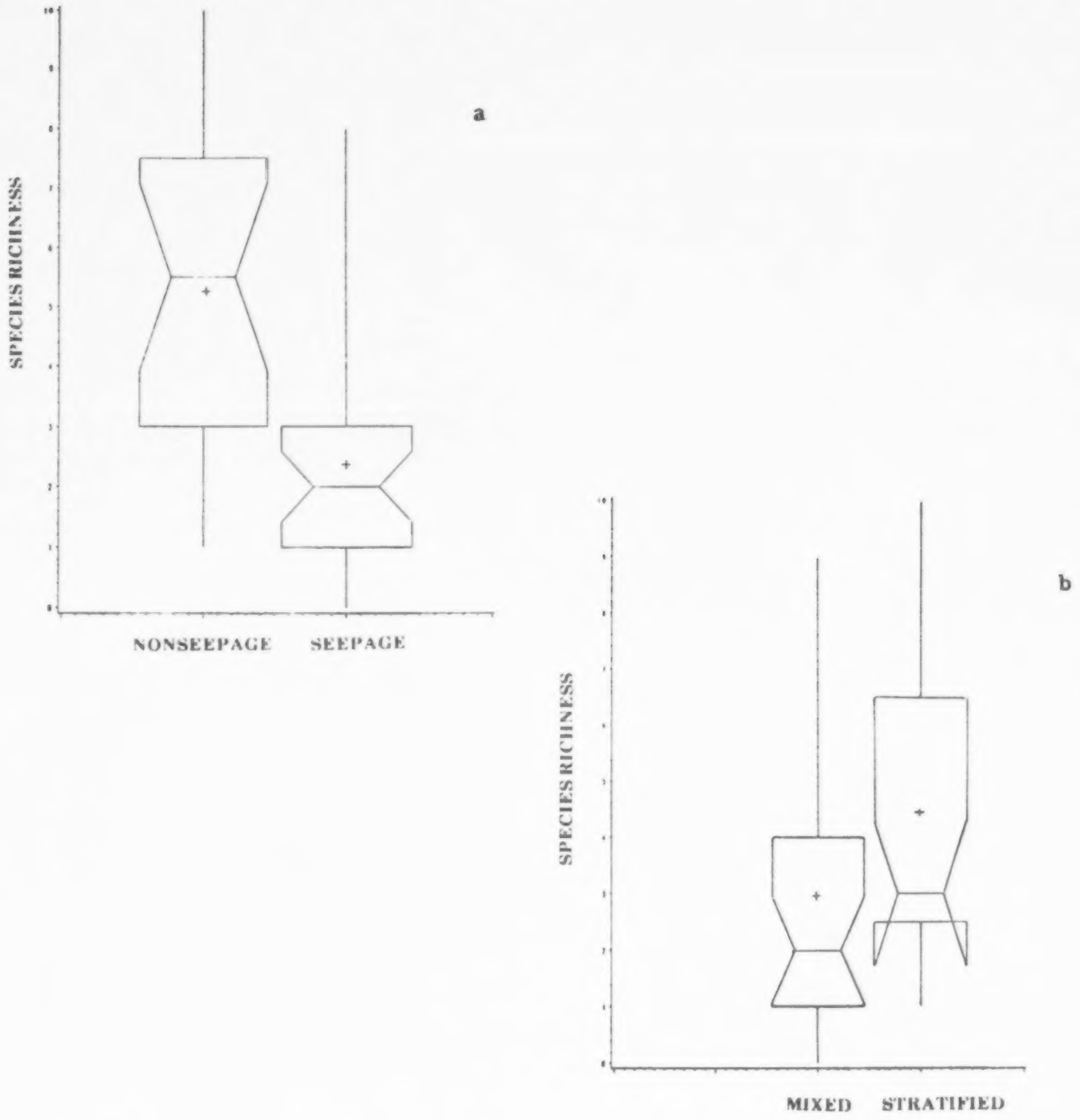


Figure 8-2. Box-and-whisker plots comparing species richness in (a) seepage versus nonseepage lakes and (b) thermally stratified versus mixed lakes. The vertical bar represents the data range; the upper and lower boundaries of the box, the 75% and 25% quartiles; the notch, the 90% confidence limits around the median; the center of the box, the median; and the cross-mark, the mean.

approach selected a slightly different model, perhaps reflecting the model instability typically associated with a high level of collinearity among predictor variables. Four variables were included in the final model by stepwise forward OLS: pH, lake type, the occurrence of thermal stratification, and SO_4 (model r^2=0.79). Stepwise backward OLS identified a five-variable model including inorganic Al, DOC, the sum of the base cations, SO_4, and the occurrence of thermal stratification (model r^2=0.82). Results from the maximum r^2 approach were consistent with results for the 49-lake data set, selecting lake pH, SiO_2, and the occurrence of thermal stratification as the best three-variable model (model r^2=0.78)(Table 8.4). In both data sets, species richness was positively associated with all three variables; i.e., all other factors being equal, lakes with more species tended to have higher pH and SiO_2 and were more likely to be thermally stratified. Silica in the model may serve as a surrogate for lake type. Nonseepage lakes had significantly higher levels of SiO_2 (Table 6.2) and higher numbers of species (Table 8.3) than did seepage lakes.

Table 8.4. Multivariate Regression Models for Species Richness

		Regression Coefficient				
Data Set	Variable	Estimate	Std. Error	p-Value	Model r^2	Condition Index
49 lakes	Intercept	-4.02	1.65	0.0187	0.69	16.0
	Lake pH	1.06	0.30	0.0010		
	SiO_2	0.46	0.14	0.0014		
	Thermal Strat.[a]	1.22	0.45	0.0095		
38 lakes	Intercept	-5.48	2.14	0.0152	0.78	17.7
	Lake pH	1.33	0.40	0.0021		
	SiO_2	0.60	0.18	0.0020		
	Thermal Strat.[a]	2.04	0.62	0.0023		

[a] Thermal stratification coded as a binary variable = 1 for lakes thermally stratified at the time of sampling and 0 for nonstratified lakes.

Interactions among predictor variables may also be important. For example, the relationship between species richness and lake pH differs significantly ($p \le 0.05$) between seepage and nonseepage lakes (Table 8.5, analysis of covariance, Snedecor and Cochran 1967). While species richness and lake pH are highly correlated in nonseepage lakes (r=0.92, Spearman's rank correlation), the relationship is somewhat less consistent in seepage lakes (r=0.60)(Figure 8-3). Inclusion of interaction terms in the above multivariate regression analyses would further aggravate problems with multicollinearity, and thus was not pursued.

Table 8.5. **Analysis of Covariance: Variations in the Relationship Between Species Richness and Lake pH, by Lake Type**

Source	Degrees of Freedom	Type I Sum of Squares	f-Value	p-Value
49 LAKES				
Model				
Lake Type	1	108.0	43.0	0.0001
pH	1	113.3	45.2	0.0001
pH*Lake Type	1	19.4	7.7	0.0079
Error	45	112.9		
Corrected Total	48	353.6		
38 LAKES				
Model				
Lake Type	1	231.2	64.4	0.0001
pH	1	136.8	38.1	0.0001
pH*Lake Type	1	28.6	8.0	0.0079
Error	34	122.0		
Corrected Total	37	518.6		

The relationship between species richness and each of the physical/chemical principal components described in Section 8.1 was also examined. Only the first principal component (determined largely by Ca, base cations, pH, ANC, and SiO_2) was significantly ($p \leq 0.05$) associated with species richness: model $r^2=0.67$ for the 49-lake data set and 0.76 for the 38-lake data set.

Clearly, species richness is influenced by a number of lake attributes including, but not limited to, factors related to lake acidity. Important variables include, at a minimum, lake pH, lake type (or SiO_2 concentrations), and the occurrence of thermal stratification. The observed relationships between species richness and each of these variables are consistent with the expected patterns and hypotheses discussed at the beginning of Section 8. The high degree of correlation among lake characteristics complicates, however, interpretation of these results. The relative importance of

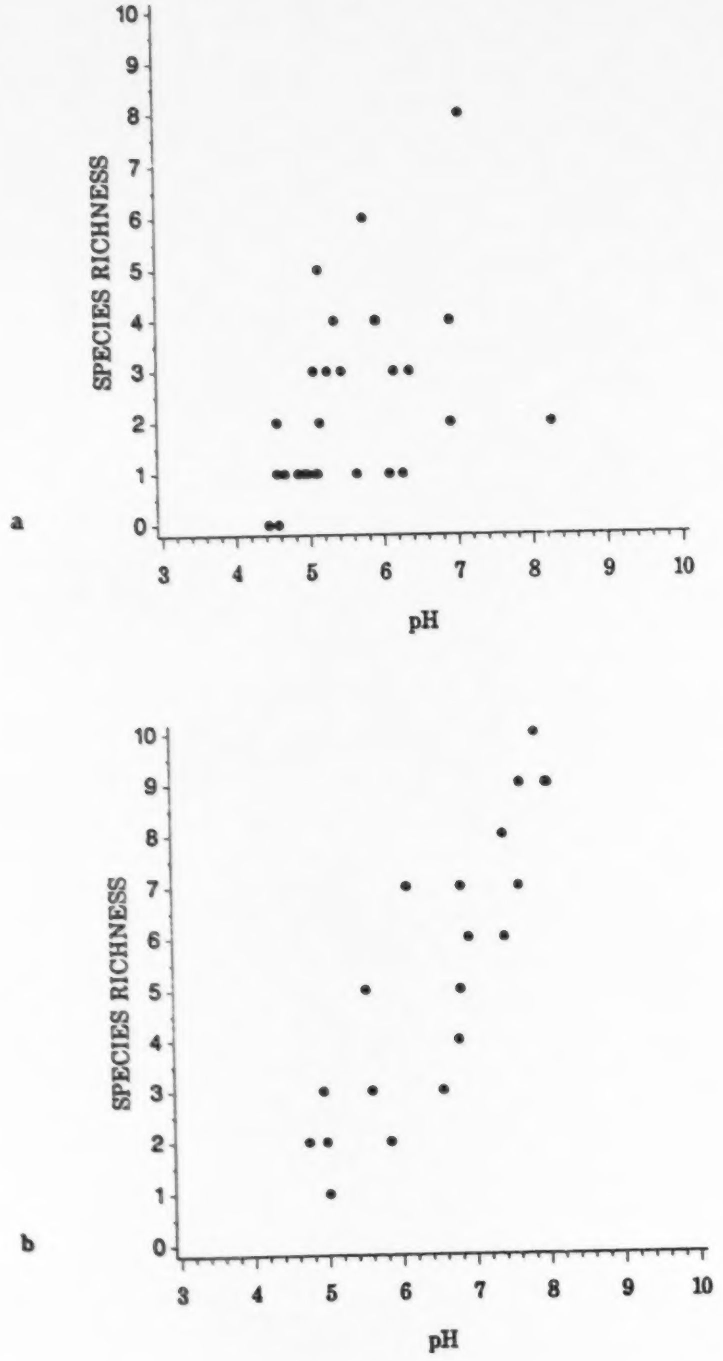


Figure 8-3. Species richness as a function of lake pH for (a) seepage and (b) nonseepage lakes.

acidity-related factors cannot be quantified with certainty, nor can the potential role of other lake characteristics, not specifically identified in these analyses, be dismissed with confidence.

8.3 FISH SPECIES PRESENCE/ABSENCE

Differences in the physical and chemical characteristics of lakes with fish caught versus those without fish caught were examined for (1) individual fish species (for species caught in at least three lakes), (2) cyprinid and darter species as a group (see Table 7.1), (3) game fish as a group (defined in Section 3.6.2), and (4) all fish species combined. As noted in Section 7.1, several fish species, especially cyprinid and darter species, were caught most effectively with beach seines, but beach seines were used in only 38 of the 49 lakes. For those fish species, and for cyprinids and darters examined as a group, analyses of lake characteristics were restricted to the 38 lakes sampled with beach seines. For all other analyses, the full data set of 49 lakes was used.

Comparisons of the characteristics of lakes with and without fish were based on the Wilcoxon rank sum and Kolmogorov-Smirnov tests for continuous variables and the Fisher exact test for binary variables. The Fisher exact test requires that fewer than 25% of the cells have expected counts less than five observations to calculate a valid chi-square. Thus, the tests for lake type and occurrence of thermal stratification could be run for only some species.

Of the 20 species tested, statistically significant differences in lake characteristics (α=0.05, adjusted for 19 tests per species, $p \leq 0.0026$) were detected only for four species: white sucker, golden shiner, northern pike, and smallmouth bass (Tables 8.6 and 8.7). All species except four (brook trout, central mudminnow, brook stickleback, and yellow perch), however, had at least one physical or chemical variable with $p \leq 0.05$. All four of these species have been reported in prior studies to be tolerant of acidity (Althshuller and Linthurst 1984, Rahel and Magnuson 1983, Schofield and Driscoll 1986) and other extreme environmental conditions (e.g., Tonn and Magnuson [1982] observed that central mudminnows are common in northern Wisconsin lakes that experience near zero DO levels under ice cover).

Of the 19 variables examined, significant differences ($p \leq 0.0026$) between lakes with and without individual fish species were found for eight variables: lake pH (for 4 of 20 species), Ca (3 species), ANC (3 species), sum of base cations (2 species), lake area (2 species), SiO_2 (2 species), SO_4 (1 species), and lake type (1 species out of 8 with sufficient numbers of lakes in each cell for a valid test). For those species for which

Table 8.6. Comparison of Lake Physical Characteristics for Lakes With (P) and Without (A) Fish Caught[a]

Fish Species/ Group	No. of Lakes with Fish		Lake Type	Area	Site Depth	Elevation	Min. DO	% DO < 4 mg/L	Therm. Strat.	Secchi Depth
	P	A								
All Fish	47	2	–	ns	ns	ns	x	ns	–	ns
Game Fish	36	13	x	ns	ns	ns	ns	ns	ns	ns
Cyprinids	16	22	x	x	ns	ns	ns	ns	–	ns
Darters	9	29	–	ns	ns	x	ns	ns	–	ns
Brook Trout	4	45	–	ns	ns	ns	ns	ns	–	ns
Central Mudminnow	5	44	–	ns	ns	ns	ns	ns	–	ns
Northern Pike	11	38	ns	*	ns	ns	ns	ns	ns	ns
Creek Chub	4	45	–	ns	ns	ns	ns	ns	–	ns
Golden Shiner	12	37	x	ns	ns	ns	ns	ns	ns	ns
Common Shiner	7	42	–	ns	ns	ns	ns	ns	–	ns
Bluntnose Minnow	7	31	–	ns	x	ns	ns	ns	–	ns
Finescale Dace	5	44	–	ns	ns	ns	ns	ns	–	ns
White Sucker	14	35	*	x	ns	ns	x	x	ns	ns
Brown Bullhead	13	36	x	ns	ns	x	ns	ns	ns	ns
Brook Stickleback	3	46	–	ns	ns	ns	ns	ns	–	ns
Rock Bass	4	45	–	x	x	x	ns	ns	–	ns
Smallmouth Bass	5	33	–	*	x	x	ns	ns	–	ns
Largemouth Bass	16	33	ns	x	ns	ns	ns	ns	ns	ns
Pumpkinseed	15	34	x	ns	ns	ns	x	x	ns	ns
Bluegill Sunfish	13	36	ns	ns	ns	ns	ns	ns	ns	ns
Black Crappie	3	46	–	ns	ns	ns	ns	ns	–	ns
Yellow Perch	31	18	ns	ns	ns	ns	ns	ns	ns	ns
Johnny Darter	3	35	–	ns	ns	x	ns	ns	–	ns
Iowa Darter	6	32	–	ns	ns	ns	ns	ns	–	ns

[a] Statistical comparisons for continuous variables are based on the Wilcoxon rank sum and Kolmogorov-Smirnov tests. Statistical comparisons for binary variables (lake type and thermal stratification) are based on the Fisher exact test. Asterisks indicate tests considered statistically significant at $\alpha=0.05$ adjusted for 19 tests per species (including both chemical and physical variables), i.e., $p \leq 0.0026$. x's indicate tests with $p \leq 0.05$; dashes indicate variables and species for which statistical comparisons could not be conducted; and ns indicates variables that were not significant, $p > 0.05$.

Table 8.7. Comparison of Lake Chemical Characteristics for Lakes With (P) and Without (A) Fish Caught[a]

Fish Species/ Group	No. of Lakes with Fish		pH	Inorg. Al	Ca	DOC	Base Cations	ANC	Color	Ext. Al	SO_4	SiO_2	Total P
	P	A											
All Fish	47	2	x	ns	ns	ns	ns	x	ns	ns	ns	ns	ns
Game Fish	36	13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cyprinids	16	22	*	ns	*	*	*	*	ns	x	x	*	ns
Darters	9	29	*	ns	*	ns	*	*	ns	x	ns	*	ns
Brook Trout	4	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Central Mudminnow	5	44	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Northern Pike	11	38	*	ns	*	x	ns	*	ns	x	ns	x	ns
Creek Chub	4	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	x	ns
Golden Shiner	12	37	*	ns	*	x	*	*	x	ns	*	*	ns
Common Shiner	7	42	x	ns	x	x	x	x	ns	ns	ns	ns	ns
Bluntnose Minnow	7	31	x	ns	x	ns	x	x	ns	ns	ns	x	ns
Finescale Dace	5	44	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	x
White Sucker	14	35	*	ns	*	x	*	*	x	ns	x	*	ns
Brown Bullhead	13	36	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Brook Stickleback	3	46	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rock Bass	4	45	x	ns	x	ns	x	x	ns	x	ns	ns	ns
Smallmouth Bass	5	33	*	ns	x	x	x	x	ns	x	ns	x	ns
Largemouth Bass	16	33	x	ns	ns	ns	ns	x	ns	x	ns	ns	ns
Pumpkinseed	15	34	x	ns	x	ns	x	x	ns	ns	ns	x	ns
Bluegill Sunfish	13	36	x	ns	x	ns	x	x	ns	x	ns	ns	ns
Black Crappie	3	46	x	ns	x	ns	x	x	ns	x	ns	x	ns
Yellow Perch	31	18	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Johnny Darter	3	35	x	ns	x	ns	x	x	ns	x	ns	x	ns
Iowa Darter	6	32	x	ns	x	ns	x	x	ns	ns	ns	x	ns

[a] Statistical comparisons are based on the Wilcoxon rank sum and Kolmogorov-Smirnov tests. Asterisks indicate tests considered statistically significant at $\alpha=0.05$ adjusted for 19 tests per species (including both chemical and physical variables), i.e., $p \leq 0.0026$. x's indicate tests with $p \leq 0.05$; and ns indicates variables that were not significant, $p > 0.05$.

statistical differences were identified, lakes without fish caught had consistently lower pH, Ca, ANC, sum of base cations, SiO_2, and SO_4, had smaller lake area, and were more often seepage lakes than nonseepage lakes. All variables except thermal stratification, Secchi depth, and inorganic Al had a calculated p value ≤ 0.05 for at least one fish species. As an example, differences between lakes with and without white sucker are illustrated in Figure 8.4 for those physical and chemical variables with $p \leq 0.05$.

Of the 38 lakes surveyed with beach seines, cyprinid species (8 species; see Table 7.1) were caught in 16 lakes; darters (2 species) were collected in 9 lakes. In all lakes in which darters were caught, cyprinids were also collected. Statistical differences ($p \leq 0.0026$) between lakes with and without cyprinids occurred for six variables: lake pH, Ca, DOC, ANC, sum of the base cations, and SiO_2 (Tables 8.6 and 8.7). Lakes without cyprinids had significantly lower pH, Ca, DOC, ANC, sum of base cations, and SiO_2 concentrations. Similar results were found for darters, with statistical differences detected for the same set of chemical variables except DOC. Of the 38 lakes sampled with beach seines, 24 (63.2%) were seepage lakes. Cyprinids and darters were caught in only 6 of these seepage lakes (25% of the seepage lakes), but in 10 of the 14 nonseepage lakes (71.4%).

For game fish and all fish species combined, no statistical differences ($p > 0.0026$) were detected for any of the lake characteristics for lakes with and without fish caught (Tables 8.6 and 8.7).

The relationship between fish species presence/absence and lake characteristics[1] was quantified using maximum likelihood logistic regression (Harrell 1983):

$$\hat{P}_i = \frac{1}{1 + e^{-\left(b_0 + b_1 X_{i1} + b_2 X_{i2} + \ldots + b_k X_{ik}\right)}}$$

where:

$\hat{P}_i$ is the predicted probability of fish presence in lake i,

b_0 through b_k are the estimated regression coefficients, and

X_{i1} through X_{ik} represent the physical and chemical characteristics of lake i.

In general, logistic regression models should include no more than m/10 independent variables, where m is the number of observations for the least frequent category of the

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[1] Logistic regression analyses were conducted for the 17 continuous predictor variables; models could not be developed for the two binary variables (lake type and thermal stratification).

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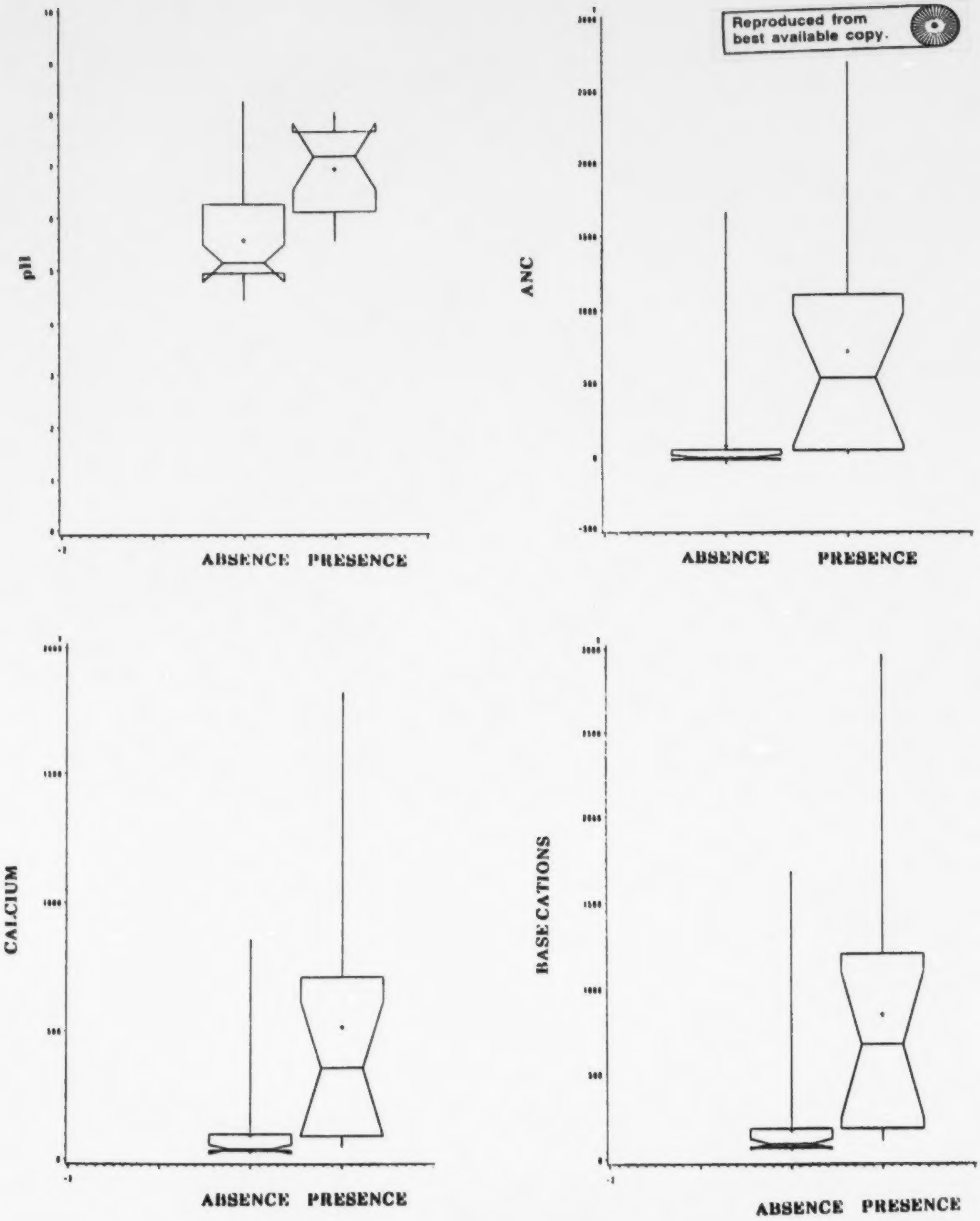

Figure 8-4. Box-and-whisker plots comparing lake characteristics with and without white sucker. The vertical bar represents the data range; the upper and lower boundaries of the box, the 75% and 25% quartiles; the notch, the 90% confidence limits around the median; the center of the box, the median; and the cross-mark, the mean.

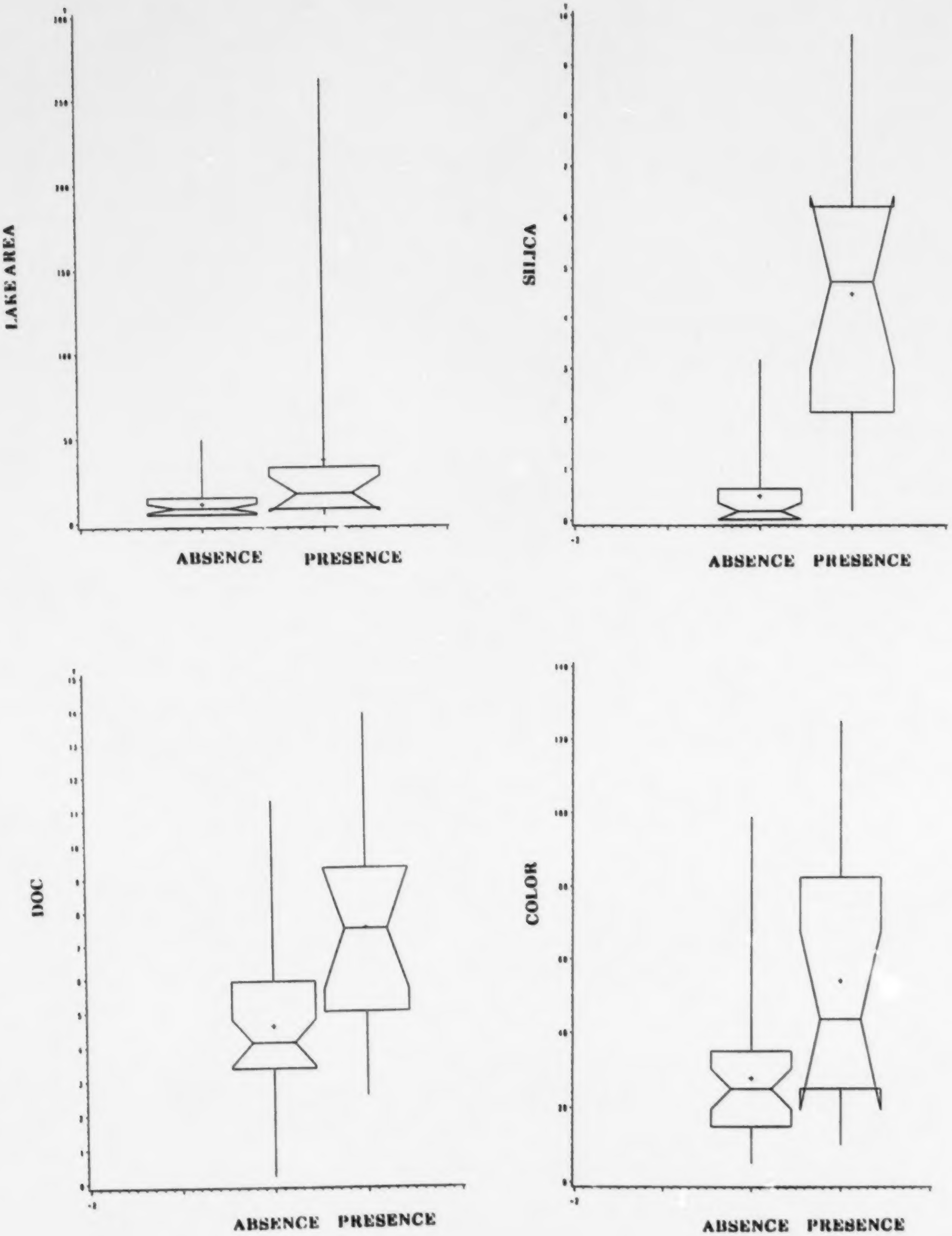

Figure 8-4. Continued.

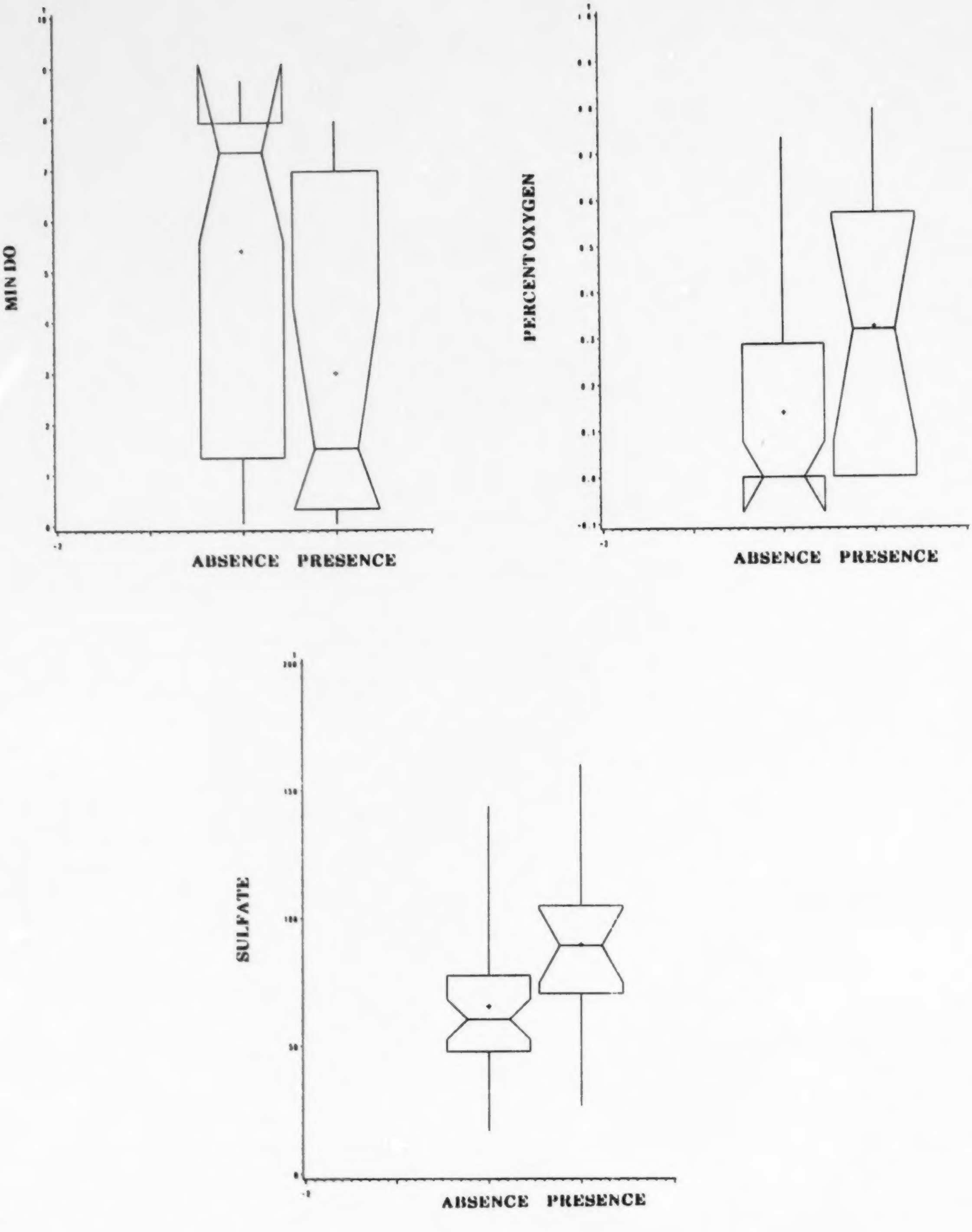

Figure 8-4. Continued.

binary response variable (i.e., the number of lakes with the fish species absent)(Harrell 1983). Thus, logistic regression models were developed only for the eight species and two groups of fish (game fish and cyprinids) caught in at least 10 lakes (see Table 8.6). For all of these species and groups, fish were caught in greater than 10 but fewer than 20 lakes (i.e., $10 < m < 20$); thus these analyses were limited to single-variable models.

For each variable of interest, models based on the nontransformed and log-transformed (base e) data were compared, using the likelihood ratio statistic (a goodness-of-fit test that compares the specified model with the unrestricted model; Statistical Analysis System [SAS] 1987). The results were generally similar to the model comparisons conducted for the OLS species richness models (Section 8.2). For lake area, elevation, Ca, sum of base cations, ANC, color, and extractable Al, for most fish species (for those models with $p \leq 0.05$ for the predictor variable) the log-transformed data resulted in a better goodness-of-fit (higher likelihood ratio) than did the nontransformed data. For SO_4, DOC, minimum DO, and proportion of the water column with DO < 4 mg/L, models based on the nontransformed data had a better goodness-of-fit. For SiO_2, lake depth, inorganic Al, and total P, results from the logistic regression analysis provided no definitive indication of the relative merits of the nontransformed and log-transformed data. For consistency with the species richness models, log-transformations were used for lake depth, inorganic Al, and total P, while values for SiO_2 were not transformed.

Estimates of the model coefficients for each of the single-variable logistic models with $p \leq 0.05$ are provided in Table 8.8. As expected, the pattern of results is quite similar to that for the nonparametric comparisons of lakes with and without fish. Five predictor variables resulted in models of fish species presence/absence significant at $\alpha=0.05$, adjusted for 17 tests per species ($p \leq 0.0029$): lake pH, ln(Ca), ln(base cations), ln(ANC), and SiO_2. All other variables examined except ln(depth), ln(Secchi depth), ln(inorganic Al), and ln(total P) had $0.0029 < p \leq 0.05$ in at least one model (for 10 fish species or groups). The probability of fish presence was consistently higher in lakes with higher pH, Ca, DOC, base cations, ANC, color, SO_4, and SiO_2; lower levels of extractable Al and minimum DO; and a higher proportion of the water column with DO < 4 mg/L; and for larger lakes at lower elevations (Table 8.8).

Principal components, derived from the principal components analysis of lake physical and chemical variables described in Section 8.1 (Table 8.2), were also considered as predictor variables of fish presence/absence in single-variable logistic

Table 8.8. Model Coefficient Estimates for Those Single-Variable Logistic Regression Models with p ≤ 0.05 for the Predictor Variable

Fish Species/Group	Likelihood Ratio	Intercept			Predictor Variable		
		Estimate	Std. Error	p-Value	Estimate	Std. Error	p-Value
ln (Area)							
Cyprinids	0.12	-3.23	1.32	0.0142	1.20	0.53	0.0232
Northern Pike	0.57	-5.40	1.61	0.0008	1.63	0.59	0.0056
Golden Shiner	0.34	-3.43	1.18	0.0038	0.92	0.44	0.0360
White Sucker	0.24	-3.51	1.20	0.0034	1.05	0.46	0.0215
ln (Elevation)							
Brown Bullhead	0.55	17.34	8.97	0.0531	-3.22	1.58	0.0423
Minimum DO							
White Sucker	0.17	0.01	0.50	0.9897	-0.22	0.10	0.0284
Proportion of water column with DO < 4mg/L							
White Sucker	0.10	-1.48	0.45	0.0009	2.51	1.20	0.0359
pH							
Cyprinids	0.92	-12.78	3.62	0.0004	2.08	0.61	0.0006
Northern Pike	0.89	-10.79	3.09	0.0005	1.50	0.46	0.0011
Golden Shiner	0.55	-7.38	2.34	0.0016	1.01	0.36	0.0050
White Sucker	0.55	-9.35	2.61	0.0003	1.36	0.40	0.0008
Largemouth Bass	0.26	-5.32	1.93	0.0060	0.76	0.31	0.0142
Pumpkinseed	0.24	-5.67	1.99	0.0045	0.79	0.31	0.0118
Bluegill	0.30	-5.43	2.03	0.0075	0.72	0.32	0.0238

(continued)

Table 8.8. Continued

Fish Species/Group	Likelihood Ratio	Intercept			Predictor Variable		
		Estimate	Std. Error	p-Value	Estimate	Std. Error	p-value
ln (Ca)							
Cyprinids	0.66	-8.11	2.39	0.0007	1.73	0.54	0.0014
Northern Pike	0.60	-5.60	1.60	0.0005	0.91	0.31	0.0033
Golden Shiner	0.47	-5.22	1.52	0.0006	0.86	0.30	0.0040
White Sucker	0.51	-6.72	1.75	0.0001	1.23	0.36	0.0006
Largemouth Bass	0.09	-3.18	1.25	0.0112	0.54	0.26	0.0398
Pumpkinseed	0.42	-4.47	1.39	0.0013	0.79	0.29	0.0059
Bluegill	0.28	-3.50	1.32	0.0079	0.53	0.27	0.0453
DOC							
Cyprinids	0.49	-3.26	1.08	0.0026	0.59	0.21	0.0046
Northern Pike	0.21	-2.60	0.82	0.0016	0.23	0.12	0.0500
Golden Shiner	0.29	-3.27	0.93	0.0004	0.35	0.13	0.0069
White Sucker	0.30	-3.01	0.87	0.0006	0.35	0.13	0.0059
ln (Base Cations)							
Cyprinids	0.79	-10.59	3.31	0.0014	2.02	0.67	0.0025
Northern Pike	0.68	-6.58	1.92	0.0006	0.99	0.34	0.0033
Golden Shiner	0.60	-6.43	1.88	0.0006	0.99	0.33	0.0031
White Sucker	0.77	-8.59	2.27	0.0002	1.44	0.42	0.0005
Largemouth Bass	0.14	-3.84	1.55	0.0130	0.60	0.29	0.0374
Pumpkinseed	0.29	-5.23	1.69	0.0020	0.84	0.31	0.0072
Bluegill	0.28	-4.19	1.61	0.0093	0.60	0.29	0.0396

(continued)

Table 8.8. Continued

Fish Species/Group	Likelihood Ratio	Intercept			Predictor Variable		
		Estimate	Std. Error	p-Value	Estimate	Std. Error	p-Value
ln (ANC)							
Cyprinids	0.72	-11.30	3.99	0.0046	2.16	0.82	0.0084
Northern Pike	0.70	-7.05	2.02	0.0005	1.07	0.36	0.0026
Golden Shiner	0.51	-6.09	1.88	0.0012	0.92	0.34	0.0060
White Sucker	0.70	-8.56	2.30	0.0002	1.43	0.43	0.0008
Largemouth Bass	0.18	-4.73	1.72	0.0060	0.76	0.32	0.0172
Pumpkinseed	0.29	-5.60	1.81	0.0020	0.90	0.33	0.0070
Bluegill	0.30	-4.65	1.73	0.0071	0.68	0.31	0.0291
ln (Color)							
Golden Shiner	0.22	-4.89	1.87	0.0090	1.10	0.52	0.0342
White Sucker	0.17	-5.95	1.97	0.0026	1.46	0.55	0.0076
ln (Ext. Al)							
Cyprinids	0.09	0.88	0.65	0.18	-0.056	0.26	0.0300
Northern Pike	0.74	0.36	0.61	0.5607	-0.87	0.33	0.0076
Largemouth Bass	0.44	0.55	0.58	0.3365	-0.62	0.25	0.0144
Bluegill	0.59	0.25	0.58	0.6623	-0.64	0.27	0.0183
SO_4							
Golden Shiner	0.46	-3.28	1.03	0.0015	0.03	0.01	0.0192
White Sucker	0.29	-2.89	0.96	0.0026	0.03	0.01	0.0229

(continued)

Table 8.8. Continued

Fish Species/Group	Likelihood Ratio	Intercept			Predictor Variable		
		Estimate	Std. Error	p-Value	Estimate	Std. Error	p-Value
SiO_2							
Cyprinids	0.25	-1.23	0.47	0.0086	0.61	0.24	0.0110
Northern Pike	0.42	-2.03	0.50	0.0001	0.38	0.14	0.0083
Golden Shiner	0.37	-1.94	0.49	0.0001	0.41	0.15	0.0061
White Sucker	0.96	-2.97	0.73	0.0000	1.25	0.39	0.0013
Pumpkinseed	0.26	-1.40	0.42	0.0008	0.32	0.14	0.0195
Principal Component 1							
Cyprinids	0.87	-0.08	0.54	0.8850	1.01	0.33	0.0019
Northern Pike	0.79	-1.61	0.45	0.0004	0.53	0.17	0.0018
Golden Shiner	0.71	-1.44	0.43	0.0007	0.53	0.17	0.0016
White Sucker	0.97	-1.44	0.51	0.0046	0.94	0.26	0.0003
Largemouth Bass	0.16	-0.79	0.33	0.0159	0.29	0.13	0.0273
Pumpkinseed	0.34	-0.95	0.36	0.0073	0.42	0.15	0.0043
Principal Component 5							
Brown Bullhead	0.50	-1.42	0.45	0.0016	-1.27	0.49	0.0088
Cyprinids	0.11	-0.30	0.35	0.3969	1.58	0.77	0.0398
Principal Component 8							
Game fish	0.29	1.16	0.36	0.0014	-1.24	0.64	0.0500
Principal Component 14							
Yellow Perch	0.11	0.61	0.32	0.0543	2.18	1.05	0.0385

regression models. For 4 of the 10 species/groups, the first principal component (defined primarily by Ca, sum of the base cations, pH, ANC, and SiO_2) was significantly associated with fish presence/absence at $\alpha=0.05$, adjusted for 19 tests per species/group ($p \leq 0.0026$); two additional species had $0.0026 < p \leq 0.05$ for principal component 1 (Table 8.8). Brown bullhead and cyprinid presence/absence were associated at $0.0026 < p \leq 0.05$ with principal component 5 (defined primarily by lake elevation and total P). Game fish and yellow perch were marginally associated ($0.0026 < p \leq 0.05$) with higher-order principal components, 8 and 14, respectively. All other comparisons between fish presence/absence and the lake physical/chemical principal components were nonsignificant with $p > 0.05$.

Given that many of the above predictor variables (e.g., pH, Ca, ANC, sum of base cations, SiO_2, lake type, and lake area; Section 8.1) are themselves highly collinear, it is not possible to determine definitively which lake attributes are actually most important in controlling patterns of fish species distribution among the ELS-II lakes. Individual predictor variables resulting in the highest likelihood ratio (goodness-of-fit) for each species in the single-variable logistic regression models were as follows: white sucker, SiO_2 (0.96)(also principal component 1, 0.97); cyprinids and northern pike, pH (0.92 and 0.89, respectively); golden shiner, ln(sum of base cations) (0.60)(also principal component 1, 0.71); bluegill sunfish and largemouth bass, ln(extractable Al) (0.59 and 0.44, respectively); brown bullhead, ln(elevation)(0.55); and pumpkinseed sunfish, ln(Ca) (0.42). In contrast, for yellow perch and game fish (which includes yellow perch), presence/absence was not significantly associated with any of the lake physical or chemical attributes considered.

The pH range of occurrence for each species caught in at least five ELS-II lakes is illustrated in Figure 8-5. Consistent with the above results, yellow perch, central mudminnow, and brown bullhead appear quite tolerant of acidic conditions, occurring at pH levels as low as 4.55-4.74. Bluegill sunfish were also caught in lakes with very low pH (4.55). Pumpkinseed sunfish, largemouth bass, and golden shiner occurred at pH levels down to 4.9-5.1, while cyprinid and darter species were generally restricted to lakes with pH > 5.7. A two-way analysis of variance (lake pH as a function of lake type and fish presence/absence, for each species caught in at least 10 lakes) indicated no significant differences ($p > 0.05$) in the pH levels associated with fish presence/absence in seepage as opposed to nonseepage lakes.

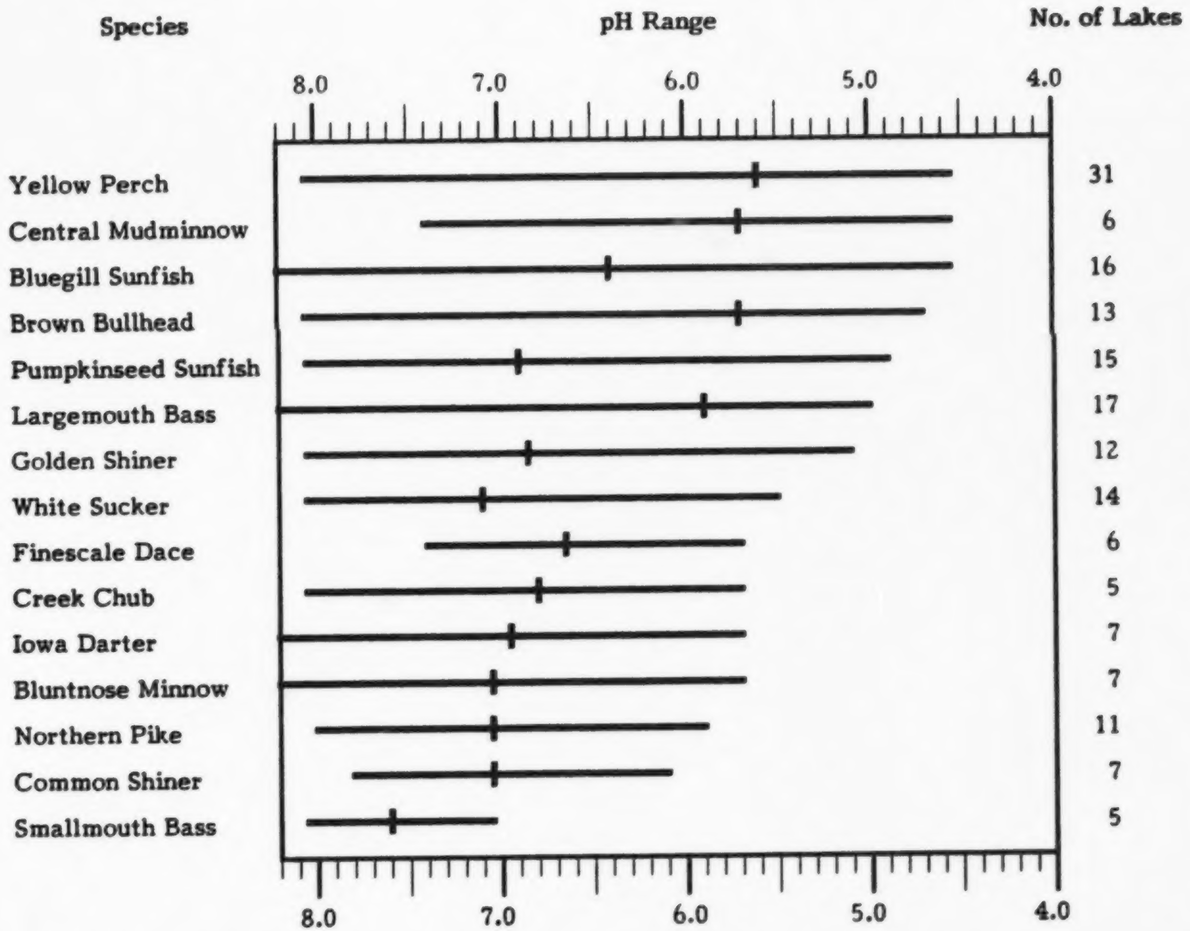

Figure 8-5. The distribution of fish species in relation to pH for the 49 ELS-II lakes. Maximum, median, and minimum pH of occurrence noted.

8.4 TOTAL CATCH AND CATCH PER UNIT EFFORT

In contrast to the large number of variables associated with species richness and fish presence/absence, nonparametric comparisons between total catch (and CPUE; all fish species combined) and the 19 physical and chemical variables of interest indicated no correlations significant at $\alpha=0.05$ (adjusted for 19 tests per fish response variable, $p \leq 0.0026$) and only three physical/chemical variables with $0.0026 < p \leq 0.05$ (depth, Secchi depth, and inorganic Al)(Table 8.3). Ordinary least-squares regression with ln(catch) (for the 47 lakes with fish caught) produced similar results. Stepwise forward OLS regression identified only ln(depth) as significant at $p \leq 0.05$. Total catch and lake depth were inversely related with a very low model r^2 (0.11). Likewise, regression of the physical/chemical principal components (Table 8.2) on ln(catch) and ln(CPUE) indicated no significant associations (all principal components had $p > 0.05$).

Among-lake patterns in catch and CPUE were also examined for the 8 individual fish species caught with gill nets and trap nets in 10 or more lakes. Only for yellow perch were any significant associations (at $\alpha=0.05$, adjusted for 19 tests per response variable per species, $p \leq 0.0026$) identified between fish catch or CPUE and lake physical and chemical characteristics (Table 8.9). Numbers of yellow perch caught and yellow-perch CPUE (for both gill nets and trap nets) were higher in lakes with lower pH ($r=-0.68$ to -0.72, Spearman's rank correlation), ANC ($r=-0.68$ to -0.71), Ca ($r=-0.56$ to -0.61), sum of base cations ($r=-0.55$ to -0.60), and SiO_2 ($r=-0.48$ to -0.56), and higher concentrations of extractable Al ($r=0.55$ for trap-net CPUE). Thus, yellow perch appear not only tolerant of acidic conditions, but actually more abundant in acidic waters with low Ca, base cations, and SiO_2.

The high variability in catch rates, discussed in Section 4.2.2, limits the utility of catch and CPUE as indices of relative fish abundance. The lack of any clear correlations between lake characteristics and fish catch for most species may result largely from this high variability in catch efficiency. Definitive conclusions regarding the relationship between lake characteristics and fish abundance are not possible based solely on the ELS-II survey data.

8.5 FISH CONDITION FACTORS

Only four fish species had adequate numbers of fish caught and measured (at least five fish per lake, including fish caught in the duplicate surveys, Section 4.2.2) in a sufficient number of lakes (at least five) for evaluation of among-lake patterns in fish condition factors: largemouth bass (7 lakes), northern pike (7), white sucker (11), and

Table 8.9. Association Between Total Catch and Catch Per Unit Effort and Lake Physical and Chemical Characteristics for Selected Fish Species[a]

	Yellow Perch			Northern Pike			Largemouth Bass		
	Total Catch	Gill-Net CPUE	Trap-Net CPUE	Total Catch	Gill-Net CPUE	Trap-Net CPUE	Total Catch	Gill-Net CPUE	Trap-Net CPUE
No. of Lakes	31	31	31	11	11	11	13	13	13
VARIABLE									
Lake Type	-	x	x	-	ns	x	-	ns	ns
Area	-0.41	-0.47	-0.37	ns	ns	ns	ns	ns	-0.60
Depth	ns	ns	-0.42	ns	ns	ns	ns	ns	ns
Elevation	ns	ns	ns	ns	ns	ns	ns	ns	ns
Minimum DO	ns	ns	ns	ns	ns	ns	ns	ns	ns
%DO < 4mg/L	ns	ns	ns	ns	ns	ns	ns	ns	ns
Thermal Stratif.	ns	ns	ns	ns	ns	ns	ns	ns	ns
Secchi Depth	ns	ns	ns	ns	ns	ns	ns	ns	ns
pH	-0.71*	-0.68*	-0.72*	0.62	ns	ns	ns	ns	ns
Inorg. Al	ns	ns	ns	ns	ns	ns	ns	ns	ns
Ca	-0.61*	-0.60*	-0.56*	0.62	ns	ns	ns	ns	ns
DOC	-0.38	-0.41	-.036	ns	ns	ns	ns	ns	ns
Sum Base Cations	-0.60*	-0.60*	-0.55*	0.64	ns	ns	ns	ns	ns
ANC	-0.71*	-0.68*	-0.71*	0.61	ns	ns	ns	ns	ns
Color	ns	ns	ns	ns	ns	ns	ns	ns	ns
Ext. Al	0.46	0.38	0.55*	ns	ns	ns	ns	ns	ns
SO_4	ns	ns	ns	ns	ns	ns	ns	ns	ns
SiO_2	-0.55*	-0.56*	-0.48*	ns	ns	0.70	ns	ns	ns
Total P	ns	ns	ns	ns	ns	ns	ns	ns	ns

(continued)

Table 8.9. Continued

	Pumpkinseed			Brown Bullead			Golden Shiner		
	Total Catch	Gill-Net CPUE	Trap-Net CPUE	Total Catch	Gill-Net CPUE	Trap-Net CPUE	Total Catch	Gill-Net CPUE	Trap-Net CPUE
No. of Lakes	15	15	15	13	13	13	12	12	12
VARIABLE									
Lake Type	-	ns	ns	-	x	ns	-	ns	ns
Area	ns	ns	ns	-0.68	ns	-0.66	ns	ns	ns
Depth	ns	ns	ns	ns	ns	ns	ns	ns	ns
Elevation	ns	ns	ns	ns	ns	ns	ns	ns	ns
Minimum DO	ns	ns	ns	ns	ns	ns	ns	ns	ns
%DO < 4mg/L	ns	ns	ns	ns	ns	ns	ns	ns	ns
Thermal Stratif.	ns	ns	ns	ns	ns	ns	ns	ns	ns
Secchi Depth	ns	ns	ns	ns	ns	-0.60	ns	ns	ns
pH	ns	ns	ns	ns	ns	ns	ns	ns	ns
Inorg. Al	ns	ns	ns	ns	ns	ns	ns	ns	ns
Ca	ns	ns	ns	ns	ns	ns	ns	ns	ns
DOC	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sum Base Cations	ns	ns	ns	ns	ns	ns	ns	ns	ns
ANC	ns	ns	ns	ns	ns	ns	ns	ns	ns
Color	ns	ns	ns	ns	ns	ns	0.61	ns	ns
Ext. Al	ns	ns	ns	ns	ns	ns	ns	ns	ns
SO_4	ns	0.56	ns	ns	ns	ns	ns	ns	ns
SiO_2	ns	ns	ns	ns	ns	ns	ns	ns	ns
Total P	ns	ns	ns	ns	ns	ns	ns	ns	ns

[a] Analyses restricted to those lakes in which the species was caught. For continuous variables, values reported are the Spearman's rank correlation coefficient. For binary variables (lake type and thermal stratification, comparisons are based on Wilcoxon rank sum and Kolmogorov-Smirnov (K-S) tests. Asterisks indicate correlations significant at $\alpha=0.05$, adjusted for 19 tests per response variable per species ($p \leq 0.0026$). For the Wilcoxon and K-S tests, x's indicate $p \leq 0.05$. For two fish species, white sucker and bluegill sunfish, all comparisons were non-significant with $p > 0.05$ (ns); therefore, no results for these species are included in the table.

yellow perch (29). Variations in fish condition factors were analyzed as a function of fish length and each of the 19 physical/chemical lake characteristics of interest, in separate two-variable OLS regression models (Table 8.10). Three-variable models with fish condition as a function of fish length, the number of fish caught per lake, and each lake attribute were also evaluated and provided similar results.

For each of the four species, fish condition factors were significantly associated ($\alpha=0.05$, adjusted for 19 tests per species, $p \leq 0.0026$) with at least one lake characteristic. For white sucker, higher condition factors (heavier fish for a given length) occurred in lakes at lower elevation; with higher transparency (Secchi depth), pH, ANC, Ca, sum of base cations, SiO_2, and total P; and lower levels of DOC, color, and extractable Al. Yellow perch condition factors were significantly ($p \leq 0.0026$) higher in shallower lakes; lakes with higher ANC, color, and SiO_2; lower transparency; a smaller percentage of the water column with DO < 4 mg/L; and higher minimum DO values; and in lakes not thermally stratified. In contrast, condition factors for northern pike and largemouth bass were significantly correlated ($p \leq 0.0026$) with relatively few lake characteristics. Northern pike tended to have higher condition factors in larger lakes with higher levels of DO. Variations in largemouth bass condition factors were significantly associated only with variations in total P: heavier fish (adjusted for fish length) occurred in lakes with lower levels of total P.

Given the large number of factors that influence fish growth and condition, and also expected variations in condition factors across the three-month sampling period, the above results must be interpreted with caution. Specific factors responsible for variations in fish condition among lakes cannot be determined from the ELS-II survey data.

Table 8.10. Summary of Results from Ordinary Least Squares Regression of Fish Condition Factors as a Function of Fish Length and Lake Physical and Chemical Characteristics[a]

	Northern Pike	White Sucker	Largemouth Bass	Yellow Perch
No. of Fish	88	282	89	1174
Lake Type	x	ns	ns	ns
ln (Area)	*	ns	ns	ns
ln (Depth)	ns	x	ns	*
ln (Elevation)	ns	*	x	ns
Min. DO	x	ns	ns	*
%DO < 4mg/L	*	ns	ns	*
Thermal Strat.	ns	ns	ns	*
ln (Secchi Depth)	ns	*	ns	*
pH	ns	*	ns	ns
ln (Inorg. Al)	ns	x	ns	ns
ln (Ca)	ns	*	ns	ns
DOC	x	*	x	ns
ln (Base Cations)	ns	*	ns	x
ln (ANC)	ns	*	ns	*
ln (Color)	ns	*	ns	*
ln (Ext. Al)	ns	*	x	ns
SO_4	ns	ns	ns	x
SiO_2	ns	*	ns	*
ln (Total P)	ns	*	*	ns

[a] In most cases, the relationship between fish condition and fish length was significant ($p \le 0.0029$). Asterisks in the table indicate significant relationships between fish condition factors and lake characteristics, adjusted for fish length [model: fish condition=f (fish length, lake attribute)] at $\alpha=0.05$, adjusted for 19 tests per species ($p \le 0.0026$); x's indicate models with $p \le 0.05$; ns indicates $p > 0.05$. Analyses only include lakes with at least five fish of the species caught.

9. REGIONAL POPULATION ESTIMATES

Based on the probability sampling frame for the ELS-I and ELS-II surveys (Section 2), data collected on fish community status for the 49 ELS-II lakes can be extrapolated to estimate fish community characteristics for Subregion 2B as a whole. In this section, regional estimates are provided for (1) the numbers and area of lakes with selected fish species and groups of fish (e.g., game fish) and (2) species richness. No regional estimates are computed for fish catch, size, or condition factors.

Two methods of regional extrapolation were used to estimate the ELS-II target population descriptions. The first approach involved a direct estimate from the ELS-II sample using the ELS-II weighting factors described in Section 2.2.2 (Table 2.3). The second approach incorporated the additional information collected in ELS-I (i.e., the lake physical and chemical data). In this case, the observed relationships between fish community status and lake characteristics for the 49 lakes sampled during ELS-II (Section 8) were assumed to hold for all lakes in the ELS-II target population. Using these relationships and the lake physical and chemical data collected in ELS-I, values for the fish response variables (and associated estimates of standard error) can be predicted for each ELS-I lake in the ELS-II target population (n=105 lakes). The ELS-I weighting factors and algorithms for regional extrapolation were then applied to calculate population estimates. Model-based population estimates were calculated only for species richness. The specific procedures for computing population estimates and appropriate measures of variance for both approaches are described in Overton (in prep.), adapted from Overton (1987).

As discussed in Section 2.2, only 49 of the 50 lakes selected for ELS-II were sampled. The lake not sampled, 2B1-065, has a small weighting factor (2.72) and represents only 0.4% of the ELS-II target population (Table 2.3). As a result, the absence of data for Lake 2B1-065 has a relatively minor impact on the ELS-II population estimates (and variances). For example, the estimated number of lakes in the ELS-II target population based on the ELS-II weighting factors for the 49 lakes sampled is 639.5 (standard error = 148.3 lakes); as compared to 642.3 lakes (standard error = 100.4) calculated from the ELS-II weighting factors for all 50 lakes, and 596.7 lakes (standard error = 58.9) calculated using the ELS-I weighting factors for the 105 ELS-I lakes in the ELS-II target population (see Section 2.2). The population estimates that follow, therefore, were calculated from the 49-lake sample without any specific adjustment for the missing data for Lake 2B1-065.

Regional estimates of the number and area of lakes with fish present were calculated for (1) all fish species combined, (2) for game fish as a group (see Section 3.6.2), and (3) for the 17 fish species susceptible to the three gear types fished in all lakes (see Table 7.1), based on the ELS-II weighting factors and direct estimation from the 49 lakes sampled in ELS-II (Table 9.1). The estimated proportion of the fishery resource (i.e., lakes with the fish species present) occurring in lakes with low ANC (< 50 µeq/L) is also indicated in Table 9.1. Fish occurred in an estimated 99.4% of the lakes in Subregion 2B (ELS-II target population), 99.5% based on lake area. Game species (i.e., yellow perch, brook trout, lake trout, smallmouth bass, largemouth bass, northern pike, and walleye) occurred in an estimated 83.7% of the lakes, 95.7% based on lake area. Yellow perch was the most common species in Region 2B, occurring in an estimated 69.8% of the lakes, 88.6% based on lake area. White sucker and largemouth bass also occurred in over 50% of the lakes in the ELS-II target population (52.1% and 50.8%, respectively; 81.6% and 36.2% based on lake area). Of the estimated 535 lakes supporting game species, 16.6% had ANC ≤ 50 µeq/L (4.0% based on lake area). Of the estimated 73 acidic lakes in the ELS-II target population, 94.9% (69.5 lakes) support one or more species of fish; 14.8% support only yellow perch.

Population estimates for species richness in lakes in Subregion 2B were calculated in three manners:

1. a direct estimate from the ELS-II sample using the ELS-II weighting factors and with species richness defined as the number of species caught with gill nets, trap nets, and angling;

2. a model-based estimate based on the OLS regression model of species richness as a function of the first 10 principal components derived from the 15 physical and chemical lake characteristics measured during ELS-I and with species richness defined as the number of fish species caught with gill nets, trap nets, and angling; and

3. a model-based estimate as described above but with species richness defined as the number of species caught in all four gear types, using data for only those 38 lakes sampled with beach seines.

The estimated mean number of species per lake from the direct estimation procedure was 5.5 (median 5.4) as compared to 5.0 species per lake (median 5.3) from the model-based approach. Inclusion of the catch in beach seines increases the estimated mean number of species (using the model-based approach) to 6.3 (median 6.1). Cumulative frequency distributions for the three population estimates (and associated 95% upper confidence limits) are presented in Figures 9-1 and 9-2.

Table 9.1. Population Estimates (Subregion 2B) of Lakes With Fish, based on Direct Estimation from the Sample of 49 ELS-II Lakes[a]

	n	N̂	SE (N̂)	Â	SE (Â)	Proportion of Lakes with Fish Present		Proportion of Lakes with Fish that have ANC ≤50 µeq/L	
						p	g	p	g
Lakes in ELS-II Target Population	49	639.5	148.3	21,995	10,934			0.233	0.066
All Fish Species	47	635.8	100.6	21,889	10,934	0.994	0.995	0.233	0.062
Game Fish	36	535.0	100.9	21,041	10,952	0.837	0.957	0.166	0.040
Brook Trout	4	95.4	56.7	2211	1837	0.149	0.100	0.020	0.006
Lake Trout	1	41.9	41.3	10,978	10,846	0.065	0.499	0.000	0.000
Rainbow Smelt	1	41.9	41.3	10,978	10,846	0.065	0.499	0.000	0.000
Northern Pike	11	267.4	80.5	16,561	10,935	0.418	0.753	0.042	0.006
Golden Shiner	12	269.8	85.1	16,323	11,016	0.422	0.742	0.038	0.009
Common Shiner	7	165.7	63.7	14,259	10,964	0.259	0.648	0.045	0.004
White Sucker	14	332.9	90.7	17,949	10,998	0.521	0.816	0.059	0.010
Brown Bullhead	13	220.2	76.6	3279	1872	0.344	0.149	0.291	0.204
Brook Stickleback	3	7.8	3.9	61	27	0.012	0.003	1.000	1.000
Rock Bass	4	143.7	70.7	13,815	10,915	0.225	0.628	0.000	0.000
Largemouth Bass	17	325.0	94.7	7961	3003	0.508	0.362	0.133	0.065
Pumpkinseed Sunfish	15	307.2	85.5	6464	2804	0.480	0.294	0.093	0.035
Sunfish Hybrid	3	27.5	17.9	405	314	0.043	0.018	0.374	0.213
Black Crappie	3	92.3	55.6	1573	981	0.144	0.072	0.000	0.000
Yellow Perch	31	446.3	91.8	19,484	10,967	0.698	0.886	0.182	0.040
Walleye	2	62.3	43.0	3083	2303	0.097	0.140	0.000	0.000
Mottled Sculpin	1	41.8	41.3	10,978	10,846	0.065	0.499	0.000	0.000

n = Number of lakes sampled with the fish species/group present.
N̂ = Estimated number of lakes with the species/group present in the ELS-II target population.
Â = Estimated lake area with fish present in the ELS-II target population.
p = Estimated proportion of lakes.

SE (N̂) = Standard error on N̂.
SE (Â) = Standard error on Â.
g = Estimated proportion of lake area.

[a] Estimates developed for those fish species reasonably susceptible to capture with gill nets, trap nets, and/or angling. Evaluation of fish presence/absence in the sample based on catch/no catch using all four gear types.

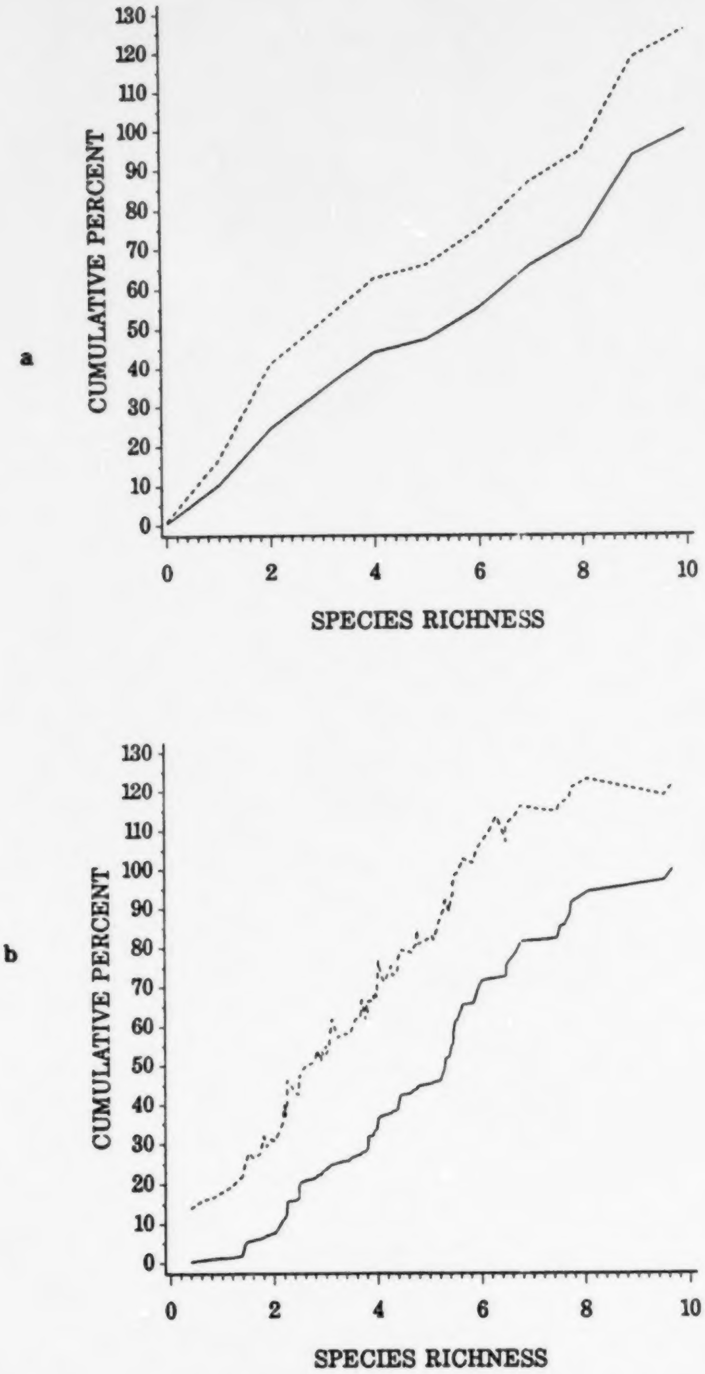

Figure 9-1. Cumulative frequency distributions of species richness (by number of lakes) for lakes in Subregion 2B, based on (a) the direct ELS-II estimate with 49 lakes and (b) the model-based approach, with species richness defined from catch with gill nets, trap nets, and angling. Dashed line indicates the 95% upper confidence limit.

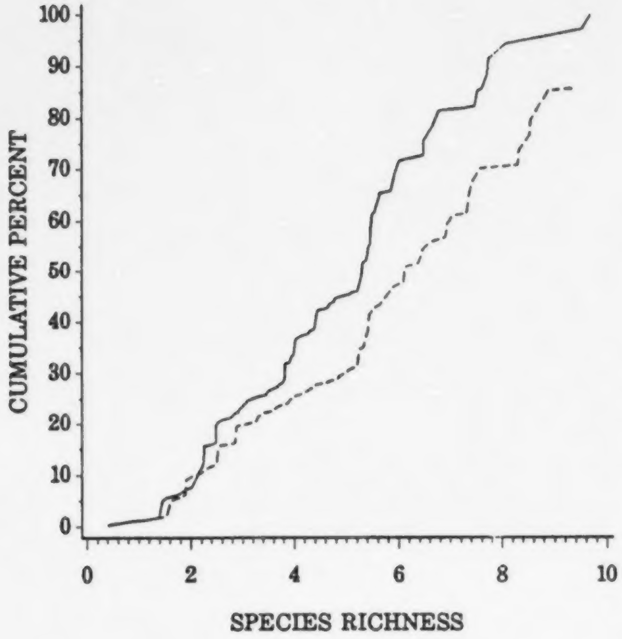

Figure 9-2. Cumulative frequency distributions of species richness (by number of lakes) for lakes in Subregion 2B, based on the model-based approach with species richness defined from catch with gill nets, trap nets, and angling (solid line) and with all four gear types (dashed line).

10. DISCUSSION AND SUMMARY

The fish species collected in the ELS-II were similar to those reported for lakes in other areas of the Upper Midwest (Wiener and Eilers 1987). Thirty-one fish species were collected in total. Yellow perch was the most common species, caught in 31 of the 49 lakes sampled and occurring in an estimated 69.8% of the lakes in the region (88.6% based on lake area). Largemouth bass and white sucker also occurred in over 50% of the lakes in the ELS-II target population.

Several of the fish species common in the region are quite tolerant of acidic conditions, as evidenced by their presence and reproduction in lakes with pH ≤ 5.0. Twelve of the 49 lakes surveyed had pH ≤ 5.0, with a minimum lake pH of 4.43. Six fish species occurred in at least one of these low-pH lakes: yellow perch (minimum pH of occurrence 4.55), central mudminnow (pH 4.55), bluegill sunfish (pH 4.55), brook stickleback (pH 4.65), brown bullhead (pH 4.74), and pumpkinseed sunfish (pH 4.94). Three additional fish species were caught in the 8 ELS-II lakes with pH 5.0 to 5.5: largemouth bass (pH 5.05), brook trout (pH 5.05), and golden shiner (pH 5.13). The apparent tolerance of these species to acidic conditions is supported by their occurrence in acidic waters in other surveys of lakes in the Upper Midwest (Rahel and Magnuson 1983, Wiener 1983, Rahel 1986, Wiener and Eilers 1987) and in the Adirondack region of New York State (Kretser et al. 1988) (Table 10.1).

While the presence of a reproducing population of fish in waters with low pH may confirm the tolerance of the species to acidic conditions, the absence of fish from such waters is not, by itself, sufficient evidence to conclude that the species is sensitive to acidity. Eight fish species occurred in at least 5 of the ELS-II lakes, but only in lakes with pH > 5.5: white sucker (n=14 lakes; minimum pH of occurrence 5.53), creek chub (n=5; pH 5.75), bluntnose minnow (n=7; pH 5.75), Iowa darter (n=7; pH 5.75), finescale dace (n=6; pH 5.75), northern pike (n=11; pH 5.90), common shiner (n=7; pH 6.10), and smallmouth bass (n=5; pH 7.05).

For some of these species, other information exists to support their classification as acid sensitive. For example, cyprinid species have been identified as particularly sensitive of low pH (pH 5.5-6.0) in laboratory and field bioassays (Johnson et al. 1987) and during the experimental acidification of Lake 223 (Mills et al. 1987, Mills and Schindler 1986), consistent with their absence at pH < 5.7 in the ELS-II. Rahel and Magnuson (1983) exposed 12 fish species from northern Wisconsin lakes to low pH levels in short-term laboratory bioassays. Cyprinids (e.g., bluntnose minnow and common

Table 10.1. Minimum pH Levels of Fish Species Occurrence in Synoptic Lake Surveys

Fish Species	Upper Peninsula of Michigan[a]	Northern Wisconsin[b]	Adirondacks, NY[c]
Acid-tolerant:			
Yellow Perch	4.5	4.4	4.5
Central Mudminnow	4.5	4.0	4.2
Bluegill Sunfish	4.5	4.5	-
Brook Stickleback	4.6	5.4	-
Brown Bullhead	4.7	-	4.5
Pumpkinseed Sunfish	4.9	4.9	4.6
Moderately Acid-tolerant			
Largemouth Bass	5.0	4.6	4.7
Brook Trout	5.0	-	4.6
Golden Shiner	5.1	5.2	4.5
Other Species			
White Sucker	5.5	4.9	4.6
Creek Chub	5.7	5.6	4.6
Bluntnose Minnow	5.7	6.2	6.6
Finescale Dace	5.7	-	-
Iowa Darter	5.7	6.2	-
Northern Pike	5.9	5.1	5.6
Common Shiner	6.1	6.2	4.9
Smallmouth Bass	7.0	5.2	5.6

[a] ELS-II data base, for those species caught in 5 or more lakes of the 49 surveyed.

[b] Wiener and Eilers (1987); species caught in 10 or more lakes of the 150 lakes surveyed.

[c] Kretser et al. (1988); species caught in 10 or more lakes of the 1123 surveyed.

shiner) were the most sensitive to low pH, while yellow perch, central mudminnows, and black bullhead were the most acid tolerant (Table 10.2). Schofield and Driscoll (1987) exposed seven species to acidic Adirondack stream water at pH 4.6. All common shiners and creek chub had died within 28 days, while 72% of the yellow perch and 100% of the central mudminnow survived. These results are consistent with the relative acid-sensitivity of the species inferred from the ELS-II survey (Table 10.2).

Table 10.2. Fish Survival Exposed to Continuously Declining pH in Laboratory Bioassays (Source: Rahel and Magnuson 1983), Compared to the Relative Sensitivity of Fish Species Inferred from the ELS-II Survey

	N	Median Survival Time (h)	pH at Median Survival Time	% Alive at Termination	Sensitivity Rank Based on: Lab. Survival	Sensitivity Rank Based on: ELS-II Field Distrib.
Blacknose Shiner	28	99	4.05	0	-	-
Bluntnose Minnow	15	105	4.00	0	1.5	3
Common Shiner	25	105	4.00	0	1.5	2
Northern Redbelly Dace	23	126	3.85	0	-	-
Smallmouth Bass	12	160	3.60	0	3	1
Mottled Sculpin	24	162	3.55	0	-	-
Golden Shiner (young)	24	174	3.45	0	-	-
Golden Shiner (adult)	18	176	3.45	0	4	4
Walleye	11	220	3.20	18	-	-
Rock Bass (adult)	21	223	3.15	14	-	-
Black Bullhead (young)	31	223	3.15	3	5	5
Rock Bass (young)	29	236	3.10	31	-	-
Black Bullhead (adult)	25	240	3.05	48	-	-
Central Mudminnow	17	240	3.05	41	6	6.5
Yellow Perch (young)	25	>240	<3.05	96	-	-
Yellow Perch (adult)	25	>240	<3.05	80	7	6.5

The absence of white sucker, northern pike, and smallmouth bass from ELS-II lakes with pH < 5.5-5.7, on the other hand, may result from factors other than low pH. In field surveys in northern Wisconsin (Rahel and Magnuson 1983) and New York (Schofield and Driscoll 1987, Kretser et al. 1988), white sucker were caught in lakes with pH levels as low as 4.6-4.9 (Table 10.1). During the experimental acidification of Lake 223, no adverse effects on white sucker populations were evident until pH levels reached 5.0-5.1 (Mills et al. 1987). Beamish et al. (1975) and Beggs et al. (1985) reported the extinction of white sucker populations from Ontario lakes at pH 4.8-5.2. Similar thresholds for the loss of northern pike and smallmouth bass in Ontario lakes were pH 4.7-6.2 (Beamish et al. 1975) and pH 5.2-5.4 (Harvey and Lee 1982), respectively. Northern pike and smallmouth bass have also been reported to occur at pH levels down to 5.1 to 5.2 in other areas of the Upper Midwest (Wiener and Eilers 1987) (Table 10.1). Rahel (1986) proposed that the absence of these two species from small, low-ANC lakes resulted from other habitat characteristics typical of these water bodies: the lack of vegetated littoral areas required by northern pike for spawning and the preference of smallmouth bass for wave-washed hard-bottomed substrates, generally rare in small, seepage lakes, as habitat and spawning sites.

Fish species distributions among lakes in the Upper Peninsula of Michigan, therefore, are influenced by a number of factors, not just acidity. In analyses of fish community structure in lakes in northern Wisconsin, Tonn and Magnuson (1982), Rahel and Magnuson (1983), Rahel (1986), and Rago and Wiener (1986) identified the importance of lake isolation (i.e., lake type and connectedness), lake area, winter anoxia, biological interactions, and lake pH and ANC as primary factors responsible for fish community composition and species richness. Results from the Upper Peninsula of Michigan were similar: fewer fish species occurred in seepage than in nonseepage lakes, in smaller lakes, and in lakes with lower levels of ANC, Ca, and base cations, and higher concentrations of extractable Al and DO.

Other than for yellow perch, no consistent relationship between fish catch, or CPUE, and lake characteristics was evident for the 49 ELS-II lakes in the Upper Peninsula of Michigan. Fish catch rates (capture efficiency) are often highly variable, making detection of patterns among lakes difficult (Ricker 1975, Bannernot and Austin 1983). Associations between CPUE and lake chemistry have been reported for some surveys (Kretser et al. 1988, Frenette et al. 1986), while other survey data sets suggest no consistent trends or relationships (Beggs et al. 1985, Haines et al. 1986). It is unclear whether the lack of a consistent pattern results from sampling variability or the absence of simple relationships between fish abundance and lake characteristics, detectable in synoptic surveys.

Likewise, fish condition factors tend to be highly variable, among seasons, among years, and among lakes, and influenced by a large number of environmental variables. In the ELS-II lakes, white sucker condition factors were significantly correlated with 11 of the 19 lake attributes evaluated; yellow perch with 8. Interpretation of these patterns to delineate effects related to acidity was not possible.

Studies in the Adirondack region of New York (Schofield and Trojnar 1980) and laboratory bioassays (Driscoll et al. 1980, Baker 1982, Ingersoll 1986) identified low pH and elevated levels of inorganic Al as the primary toxic agents in acidic waters. In the

ELS-II survey, however, relatively little of the among-lake variation in fish community status could be attributed to inorganic Al. Concentrations of Al are often low in seepage lakes (Eilers et al. 1988); sixteen of the 20 acidic lakes sampled were seepage lakes and all but one of the lakes sampled had levels of inorganic Al < 60 µg/L. As a result of these low concentrations, inorganic Al may play a relatively minor role in the effects of acidification on fish populations in the region.

Despite the relatively large numbers of acidic and low-pH lakes in the Upper Peninsula of Michigan, Subregion 2B, most lakes in the area (over 99% of the ELS-II target population by number and by lake area) support at least one fish species. Eighty-four percent of the lakes (96% of the lake area) support at least one game species (defined as yellow perch, walleye, largemouth and smallmouth bass, brook trout, and lake trout). Of the estimated 636 lakes that currently support fish in Subregion 2B (in the ELS-II target population), 23.3% have ANC ≤ 50 µeq/L and thus are potentially sensitive to future effects from acidic deposition; an estimated 16.6% of the lakes with game fish currently have ANC ≤ 50 µeq/L.

The ELS-II data base on fish communities in lakes in Subregion 2B provides a regional perspective on the current status of the fishery resource in the Upper Peninsula of Michigan and adjacent northeastern Wisconsin. It cannot be used, by itself, to determine whether aquatic resources in the region have been impacted by acidic deposition, nor to determine specific causes for observed among-lake patterns in fish communities. The ELS-II may, however, provide insight into processes of importance in controlling fish population responses to acidification and serve as a baseline for future analyses of trends in fish communities in the area.

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